# Locomotive Management

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CANADIAN NATIONAL RAILWAYS

LOCOMOTIVE MANAGEMENT
HEAT AND SUPERHEATERS

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Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Printed in U. S. A.

INTERNATIONAL TEXTBOOK PRESS
Scranton, Pa.

84310

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## LOCOMOTIVE MANAGEMENT

## HEAT AND SUPERHEATERS

# LOCOMOTIVE MANAGEMENT

Serial 2501 Edition 2

## CARE AND OPERATION OF THE STEAM LOCOMOTIVE

### INSPECTION OF LOCOMOTIVES

**1. Importance of Inspection.**—The degree of success attained by an engineer depends not only on his ability to operate a locomotive in such a manner as to obtain the greatest amount of work from it with the least possible expense for fuels, lubricants, and running repairs, but also on the care he exercises in inspecting, and properly reporting the work required on the locomotive. Inspection and the making of an accurate and intelligent report is a very important duty in the successful operation of a locomotive. Engine failures, delays in service and probably accidents that involve the loss of life, or damage to property, may in a great measure be prevented by thorough inspection. Frequent and careful inspection of all of the parts of the locomotive is therefore essential to the engineer's success, since by this means defects can be discovered as soon as they develop, and by properly reporting same and seeing that repairs are made, the cost of running and the back shop repairs will be kept down. The locomotive can then be kept in such shape that if operated properly, its regular tonnage will be hauled and satisfactory running time made with the least expense for fuel and lubrication.

**2.** Some railroads employ locomotive inspectors, whose duty is to thoroughly inspect and test each locomotive when it

comes to the roundhouse, and report the defects discovered. However, this practice does not relieve the engineer from also inspecting and reporting defects discovered, either in the inspection or the operation of the locomotive. The engineer should inspect his locomotive before he leaves the roundhouse or terminal, and whenever he has occasion to oil the locomotive on the road, he should make it a practice to inspect the important parts. In this way a fairly good inspection can be made at various times during the run. At the completion of the run, he should give the locomotive a thorough inspection, and report all defects discovered at this time or during the run.

3. **Inspection Before Attaching to Trains.**—The engineer and the fireman should report for duty in ample time to inspect and oil the locomotive so as to be sure that it is in proper condition and fully equipped for making the run. They should examine the bulletin board; compare their watches with standard clocks, provided there is one at that point; and examine the work report book and see whether the defects reported from the previous run have been repaired.

On some roads the roundhouse staff is responsible for the filling of the lubricator, flange oilers, marker or other lamps, grease cups, and lubrication of the journal boxes; as well as putting on the locomotive, the supplies of oil, grease, waste, spare-air and steam-heat hose, flags, fusees, torpedoes, and whatever tool equipment or supplies that the rules and regulations of the road require to be carried on the locomotive. However, the engineer should see that this work is done. Where it is not done by the roundhouse force, the fireman usually does it under the direction of the engineer.

The first thing the engineer should do when getting on the engine is to inspect as far as the brick arch will permit, the crown staybolts, staybolts, flues, arch tubes, syphons, and sheets; leaky flues will be indicated by the appearance of water on the flue sheet below the arch.

The engineer should personally inspect, or have the fireman examine the grates to see that they are level and not tipped, which would cause the fire to drop into the pan and burn the fin-

gers off. He should see that the fire is in proper condition, and that the firing tools are on the engine. The ash pan should also be examined to see that it is clean, and the ash pan gear should be operated to see that it is in working order; that the ash pan doors or slides close properly, so that there are no openings that would permit live coals to escape and start fires.

4. The injectors, lubricator, feedwater pump, compressor, air brake, stoker, booster, power reverse gear, superheater damper rigging, cylinder cocks, headlight, grate shaker, and firedoor should be operated to see that they are working properly. The sand box should be examined to see that it is filled, and the sander should be tested to see that it operates properly, and that the pipes lead the sand to the center of the rail and not to one side. On most roads, the testing and inspecting of these parts is done by the roundhouse force, but this does not relieve the engineer of his responsibility.

During his inspection of the locomotive, he should note particularly whether defects reported at the completion of the previous trip have been attended to; that visible parts that had been removed have been replaced properly, that all bolts, nuts, and cotters are secure; and that when repaired, all bearings such as crankpin brasses, guides and crossheads, are not so tight as to run hot. The height of the water in the boiler should be observed and the water gauge and the gauge cocks should be tested. The testing should be done thoroughly because the safety of the crew and the lives and property of others depend on their proper operation. These devices should be blown out by the engineer or the fireman before the engine is taken from the roundhouse, and a careful inspection made for defects, such as leakage or restricted openings, or anything that would tend to show an incorrect water level. To blow out a water gauge properly, open the drain cock and close the bottom valve; the water should then disappear from the glass, and steam should blow freely from the drain cock. If the steam does not discharge freely when the top valve is open, then the passage through the upper valve body is partly or wholly closed, or the upper end of the glass is obstructed.

Next close the top valve and open the bottom one; then water should blow freely from the drain cock. If not the passage in the lower valve body is partly or wholly closed.

5. The gauge cocks are tested by opening them and seeing whether the steam or the water flows from them in a good stream. Both the water gauge and the gauge cocks should be tested occasionally during the trip. The practice is to equip modern locomotives with water columns, which also should be tested to see that the try cocks and the water glass give the same reading.

The main reservoirs should be drained of all condensation, also the drain cocks on the air compressor should be opened before starting it, to relieve condensation. The compressor should be started slowly until sufficient pressure has been built up in the main reservoir to cushion it, then the steam valve can be opened up. Before starting the compressor, the oil feed should be adjusted so as to feed extra oil to the steam cylinder on account of the condensation washing the lubricant off the walls, then after a few minutes the feed should be adjusted to the regular amount. The air pressure shown on the gauges should be checked to determine whether the compressor governor and feed valve are working properly. All condensation in the brake pipe and in the air hose between the engine and the tender should be blown out by opening the angle cock at the back of the tender. The brake should be tested by applying it with each brake valve and the signal equipment tested by opening slowly the valve on the signal line at the rear of the tender, and noting whether the air discharges freely and that the whistle sounds promptly. The engineer should make sure that he has a full supply of fuel and water.

6. The engineer must oil the parts of the engine not attended to by the roundhouse force. The oiling should not be done more than ten or fifteen minutes before leaving the terminal, because better results will be obtained than if the oiling is done earlier, especially in warm weather. In very cold weather, it may be necessary to oil the locomotive before leaving the roundhouse due to the parts becoming so cold that

the oil is chilled, and will not run into the bearings if the oiling is done after the engine leaves the roundhouse.

On roads where it is the duty of the engine crew to take the engine out of the roundhouse, they should see before moving the engine that the smokejack is clear of the stack if it is of the lowering type, also that all tools and blocks have been removed, that the roundhouse doors are opened properly and that the turntable is in proper position.

In severe weather, the steam-heat valve in the cab should be opened enough to permit a small discharge of steam through the steam-heat hose at the rear of the tender.

7. **Inspection at End of Run.**—The engineer should bring his engine to the roundhouse with about three gauges of water in the boiler so that the injectors will not have to be operated when the fire is low. Water put into the boiler at such a time has a tendency to cause the tubes and flues to leak. The fire should not be so heavy that fuel will be wasted when dumping it, or so dead that the tubes and flues would be caused to leak. On engines equipped with mechanical stokers, the coal elevators, conveyors or hoppers should be free from coal in order that the different parts may be conveniently tested and if necessary be repaired by the repair man. In cold weather the feedwater pump should be drained and heater put on the injectors to prevent the hose from freezing up.

In inspecting the locomotive the engineer should start forward from the right cab steps and inspect the engine on that side, then the front, and along the other side of the engine and tender, the back of tender, and lastly inspecting the tender on the side from which he started, thus making a complete circuit of the locomotive. He should inspect the main and side rods for hot bearings; loose, broken or worn brasses; loose or worn knuckle pins; for loose bolts or flaws in the rods; crossheads slack in guides; loose or worn wrist pins; defective crosshead keys; crank pin washers loose or missing; hot or worn driving boxes, engine and tender truck boxes; broken springs, or springs with leaves broken; springs shifted in spring buckle; spring rigging broken or out of place; breaks

in frame, tires, and wheel centers; tires shifted on center; sharp flanges; excessive side play in engine truck, trailing truck or driving wheel boxes; defects in brake gear, etc. He should also carefully check the parts of the valve gear for any defects and should see that all the oiling devices are in proper condition.

8. On locomotives equipped with grease cellars in the driving boxes, the indicators should be examined to ascertain if there is sufficient grease in the cellars or if it needs replenishing. Among the defects which are more easily detected while the engine is working are: leaky valve or piston-rod packing; defective valve or piston rings; defective cylinder cock rigging; leaky cylinder cocks; safety valves which blow down the steam pressure too low before seating; leaking throttle or steam pipes; engine not steaming properly due to air leaks in smokebox or draft arrangement in the smokebox not properly adjusted, all of which waste steam and cause extra fuel and lubricants to be used thus putting extra demands on the boiler. Other defects which may develop or be detected during the trip are valves out of square; defective brake gear; steam blows; pounds in boxes, rods, etc.; hot bearings; defects in injectors; feedwater pump; reverse gear; headlight; stoker; air compressor; booster, etc.

The engineer should consult with the fireman regarding any defects which may have come to his notice such as faulty stoker, grate shaker, grates, ash pan, ash-pan rigging, brick arch, crown, flue, and side sheets in firebox, etc.

The engineer should report and see that the tender hose strainers are cleaned frequently. A defect chart is shown in Fig. 1, the text gives in an abbreviated form the rules that relate to defects as contained in the instructions entitled *Laws, Rules and Instructions for Inspection and Testing of Locomotive and Tenders and Their Appurtenances,* issued by the Interstate Commerce Commission. The figures in parenthesis refer to the number of each rule.

9. **Work Reports.**—The ability to make a clear and concise work report is the duty of every engineer, and he should

not lose sight of his responsibility in this regard. Most roads make a practice of pooling their locomotives, which, if the locomotives are properly maintained, results in getting more service out of the engines and a greater flexibility in handling the business to be done. However, whether the engines are assigned or pooled, the engineer's cooperation in making out proper reports of all defects is essential in maintaining the engines in a proper condition to do their work. There are many defects that can be detected to best advantage when the engine is in service, as already mentioned, which should be reported by the engineer bringing in the engine, or otherwise an engine failure may occur on the next trip. If a defect is not serious enough to cause an engineer to give up his train it may cause detention and considerable more work for the engineer and fireman in getting over the road, all of which might have been avoided if a proper report had been made out and the defective part repaired.

In making out the report, the defective parts should be stated in such terms that the roundhouse staff can quickly locate them and make the repairs without delay, otherwise considerable time will be lost trying to locate the trouble and if the time is short between trips or turn arounds it may be too late to do the work when the defect is found. For example, to report that a valve is blowing is indefinite, unless, mention is made as to whether it be the right or left one.

In reporting trouble or failure to wheels of an engine truck, driving wheel, trailing truck or tender truck, the wheels should be designated by giving, first the side of the engine on which it is situated and second, the number and name of the wheel. The engine truck wheel, driving wheel and tender truck wheel nearest to the pilot is designated as No. 1, and the others are numbered consecutively. Another method is to designate the wheels by number only, beginning with No. 1 at the pilot and then numbering them consecutively to the rear of the tender. Thus for a Mikado or Pacific type locomotive wheel No. 6, right side, would refer to the trailing truck wheel, and wheel No. 7, right side, would designate the first wheel of the front tender truck.

**10. Theory of Lubrication.**—The theory of lubrication is a subject on which considerable could be written, but as far as enginemen are concerned, a general outline should be sufficient.

The bearings of every machine, regardless of how much effort has been taken to have them as smooth and true as possible, will, if the surfaces are examined under a microscope, be found to have projections on the apparently smooth surfaces. The projections on the bearings interlock with those on the journal and cause friction when the parts move on each other, thus generating heat and causing a loss of power in the machine. If allowed to run, the parts will continue to heat and enough heat may develop (depending on the load and speed) to cause the bearings to become overheated, cut or worn away.

By lubricating the parts with some substance which will form a film between the two surfaces, the friction may be cut down, because the friction of the lubricant is less than the solid friction of the bearings. The lubricating film does not improve the condition of the bearing but one film adheres to the bearing, and one to the journal, the films sliding, one on the other. The metal parts are thus separated by a film of lubricant, and if maintained in that condition there can be no wear on the parts. In most cases, however, it will probably be found that the journal and its bearings are not completely separated and a certain amount of wearing and heating results. The lubricating film helps to dissipate the heat that is generated, and the nature and quality of lubricant used, as well as the frequency and method of applying the lubricant will determine the amount of friction in the bearings and the heat developed.

**11. Theory of Lubrication With Waste.**—Waste that has been soaked in engine oil is used to lubricate the journals of engine-truck, trailing-truck, and tender-truck axles. The waste has sufficient elasticity to hold up against the journal, and the capilliary attraction of the waste is depended upon to conduct the oil upwards to the journal. The required elasticity to hold the waste constantly against the journal is as important as the effective absorption of the oil. It then follows that any con-

dition that impairs the elasticity of the waste or its capilliary attraction also effects the proper lubrication of the journal, thus the constant shocks received when running tends to pack the waste and thus impair its elasticity; at times the waste will become packed so hard that no lubrication will be delivered to the bearing at all. Also the surface strands of the waste, due to continual contact with the rotating journal will glaze over and thus destroy the capillary action.

Cotton waste is highly absorptive but it lacks the degree of elasticity required to keep it up against the bottom of the journal. The various qualities of wool waste are generally considered inferior to cotton from a standpoint of capillarity, but possess a higher degree of elasticity. In some cases a waste is used that contains equal parts of thread cotton and a good grade of long fiber to provide the necessary springiness, combined with a small part of other resilient fibers.

**12. Theory of Grease Lubrication.**—Grease is generally used to lubricate the journals of the driving wheels and their crankpins. The grease is kept in contact with the journals by means of a spring actuated plate, and grease plugs are used to force the grease on to the surfaces of the crankpins.

The grease used in the driving boxes is called driving journal compound, and that used on the crankpins is called rod cup grease. Rod cup grease has a lower melting point than driving journal compound; the former melts at about 230° F. and the latter at 275° F. Grease is less adhesive than oil and ordinarily it will not adhere to the surface of the journal to such an extent as to come between the journal and the crown brass. To feed grease properly requires an action between the journal and the crown brass that will serve to force the grease upwards between them. This action is secured by relieving both edges of the brass about $\frac{3}{8}$ inch above the horizontal center line of the journal on the main bearings and about 1 inch on all others. This results in a slight back and forth movement of the journal as the piston reverses; the grease is then compressed between the journal and the brass when the slack is taken up, and is then forced up around the journal through the grease grooves

that are cut in the brass. There is enough slack in the main- and side-rod brasses to permit the cup grease to be fed to the crank pins in the same manner. However, there is no back and forth thrust applied through the medium of rods to the engine-truck, the trailing-truck and the tender-truck journals, and this makes it impossible to use grease as a lubricant for these journals with the boxes as ordinarily constructed.

### COMPOSITION OF OILS

**13.** In the early history of railroading before the discovery of mineral oils, locomotive valves and cylinders were lubricated with animal or vegetable oils. The flash point of these oils was low, but as the steam pressures were not then high, a fairly satisfactory service was obtained. The development of mineral lubricants made it possible to manufacture an oil with a much higher flash and burning point than were previously practicable. It also made higher boiler pressures possible, and eventually the superheating of steam.

There is a general impression that valve oil is entirely a mineral oil, but this is not the case, as the best valve oil contains not less than 5 per cent. acidless animal oil. The lighter grades of lubricants such as car, coach and engine oils may be straight mineral oils or oils compounded with lead oleates as a base. In addition such oils as castor, rape, tallow, lard, neatsfoot, whale, wool oil and fish oil are used in compounding the lighter grades of lubricants. The actual composition of the oil does not by any means tell the whole story, and generally speaking the analysis is a very poor guide for the selection of an oil for any particular lubricating purpose. The flash point, burning point, and the viscosity may tell something about the physical characteristics of the lubricant and these points may be covered by specifications, but the only reliable way to tell whether or not an oil is satisfactory is to test it under actual operating conditions.

**14.** By some it has been considered essential that the flash point of valve oil should be as high or higher than the temperature of the steam in which it is used. In locomotive practice

this is not necessary provided that sufficient steam is kept in the cylinders to exclude the cold air and the smokebox gases.

To manufacture a valve oil with a flash point of over 650° F., the average temperature of superheated steam, so much of the lubricating properties would be removed and so much carbonaceous matter left as a residue, that the oil would not prove to be a satisfactory lubricant. The usual flash tests for valve oils range from 525° F. to 575° F. and the fire tests from 580° F. to 650° F. and the viscosity at 212° F. 150 seconds. At the same time, the lubricating qualities of a valve oil, that conforms to these requirements, can only be determined by a service test under actual operating conditions.

**15. Quantity of Oil.**—The quantity of oil required by the various parts of an engine will depend on the size and type of the engine, the work performed and the time occupied in doing that work, the conditions under which the engine is worked, and the quality of oil used. All the bearings and wearing surfaces should be oiled with just sufficient oil to lubricate them thoroughly. Large locomotives require more oil than do locomotives of a smaller type, because they have more and larger journals and wearing surfaces; thus a heavy freight engine with small drivers that takes from 18 to 24 hours in getting over a division should be allowed more oil than a large-wheeled engine with a light train that, perhaps, would require only 7 or 8 hours to travel the same distance. The same rule may be applied to the use of valve oil. A large, heavy engine with a slow train may make only a low mileage to a pint of valve oil, while a light engine on a light train and running at good rate of speed, will have no trouble in doubling the distance. Generally from 1 to 3 pints of valve oil is allowed for each 100 miles and from 1½ pints to 4 pints of engine oil.

**16. Where Lubrication is Applied.**—The principal points where lubrication is applied to a locomotive is shown in Fig. 2; engine oil is used on the shoes and wedges, in the engine-truck, trailing-truck, and tender-truck boxes, on the front end of the main rod, the knuckle pins in the side rods, the cross-

heads, the valve gear and the engine-truck, trailing-truck and driving-wheel hubs. The journals of the driving wheels and the main and side rod bearings are generally lubricated with grease except the front end of the main rod, but in cases where oil is used for these parts they should receive proper attention before starting on the run.

The oiling of the engine, trailing, and tender truck boxes is generally attended to by the roundhouse staff and the packing should be examined and worked up frequently to keep it in proper shape so that it does not become glazed or soggy and clear of the journal; the other parts of the locomotive should be oiled just before leaving the terminal as better results will be obtained if the oiling is done at that time. Any of the above parts that have oil cups should have the feeds adjusted as required to properly lubricate them, care being taken not to overflow the cups or waste the oil unnecessarily when filling. No rule can be given for the frequency of oiling due to the factors previously mentioned. If practicable it is good practice to oil these parts every 75 or 100 miles, but the engineer has to do this work when the opportunity occurs and will be governed by the conditions met with on the run.

**17.** Such parts as the stoker cylinder, air compressor, feedwater pump and booster engine, should have the lubricator opened and feeds adjusted as soon as they are put in service and any other parts of these devices that require lubrication should be oiled before starting.

When grease cups are applied to the rods they should be filled with grease at the roundhouse and the plug screwed down until a small amount of grease squeezes out between the bearing and the pin; when oiling the locomotive on the road the grease plug should be screwed down or more grease put in the cups as required.

When oiling any parts that have packing in the oil cups or cavities, care should be taken not to disturb it with the spout of the can because the dirt which may have collected on the top of the packing is liable to get into the oil holes and be carried into the bearing and may cause heating.

18. In cold weather the engine should be oiled in the roundhouse while the parts are warm so that the oil will run into the different bearings. If the oiling is put off until the engine is on the train the different parts may be so cold that the oil will thicken and not run into the bearings and heating may result; also, it may be necessary to use a lighter oil on the valve gear during severe cold weather. When oiling an engine in the engine house due to cold weather this condition should be taken into account with regard to the amount of oil applied.

In severe cold weather when the grease is hard, it is good practice to put a small quantity of oil in the grease cups by punching a hole through the center of the grease with a small rod until it touches the pin and then filling the cavity with oil. It takes some time for the grease to soften and pins may become very hot before the grease begins to lubricate them unless oil is applied as described. This is also good practice in snow storms, sleet or heavy rain, especially on the middle connections and the main rods.

As it is general practice to work steam at all times on superheated locomotives, the oiling of the piston and valve rods will require no attention from the engineer, for if the valves and cylinders are properly oiled the rods will be taken care of at the same time by the oil from the lubricator.

## REPACKING ENGINE TRUCK, TENDER TRUCK, AND TRAILING TRUCK BOXES

19. **Materials Used.**—The materials used for packing boxes should consist of either cotton or woolen waste that has been thoroughly saturated with lubricating oil; long-fiber waste being more preferable than short-fiber waste, and wool waste, though more expensive, being greatly preferable to cotton waste. The waste should be carefully pulled apart, placed in a saturating vat and kept completely submerged in the lubricating oil at a temperature of not less than 70° F., for a period of at least 48 hours to insure thorough saturation. Waste soaked in this way will give much better service than waste that has been soaked for a short time only, for the reason that the former will be thoroughly sat-

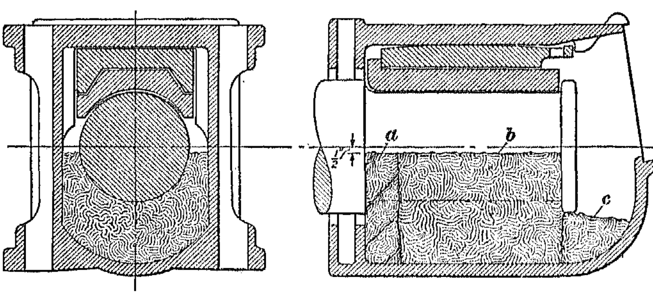
urated with oil while the latter is not. At the end of the saturation period the excess oil should be drained off by placing the waste on a wire netting, leaving from 3 to 3½ pints of oil to each pound of dry waste so that the waste is not swimming in oil but is in a resilient or elastic condition. As the oil continues to drain it should be drawn off from the bottom of the vat and poured back over the top of the waste, or the waste turned over at least once each 24 hours. When carried on an engine ready for use the packing or dope, as it is called, should be kept in a covered bucket made for the purpose in order that cinders and grit will be kept out. Among other tools, all engines should be provided with a set of packing irons, which consists of a hook for pulling the packing out of the boxes and a tool to be used for pushing the packing into the boxes and around the journals.

In order to allow the brass to be taken over the collar on the end of the journal without having to raise the box too high, an iron wedge, or key (sometimes called a slide), is placed between the top of the brass and the top portion of the oil box. This wedge fits behind a lug in the top of the oil box which prevents it from working out. To remove a wedge, raise the box to such a height that the wedge will slip out under the lug; this will give enough room to lift the brass over the collar. After replacing a brass, the wedge must be replaced and the box let down before packing. One or two spare tender brasses should always be carried in the tender tool boxes.

**20. Repacking the Boxes.**—Before repacking a journal all the old packing should be removed and the oil cellar and the box thoroughly cleaned of all dirt, scale, grit, and sand. If there is any water in the box it should be removed.

To properly repack a tender truck box a piece of moderately dry packing in twisted form as shown at *a* in Fig. 3, should be placed in the extreme back of the box to better exclude dirt and avoid waste of oil and properly lubricate the fillet on the journal. This packing should be well up against the journal but it should not extend above the center line as this increases the chances of waste grabbing. After the roll

has been properly placed, the rest of the packing *b* should be applied by picking it up with the hands and spreading it evenly over the entire mouth of the box. Some of the packing should be allowed to overhang outside of the box, and more should be added before the final strands are packed in the box under the journal, the result being that all of the packing is bound together in one mass because it is fed in a continual strand under the journal. The packing should be firmly applied under the journal to avoid settling away and in so doing the packing iron should be kept to the bottom of the box until it is completely packed to within ½ inch of center line of the



(a) FIG. 3 (b)

journal. No more packing must be applied than will fill the box flush with the inside of the collar as shown. The packing should not be too tight, but should be tight enough to overcome any tendency to settle away from the journal and there should be no loose ends which might work under the journal bearing. In order that the lateral motion of the journal will not work the packing out, a plug, made of firmly twisted packing, as shown at *c*, Fig. 3, should be placed in the bottom of the box. This plug also acts as a support in keeping the packing under the journal. When the work is completed there should be no loose ends of packing hanging out of the box as they would tend to syphon out the oil.

Trailing-truck boxes are packed in the same manner as the tender truck except that the roll *a* Fig. 3 is not applied.

**21.** In repacking engine-truck boxes the cellar should be taken down, and all the old packing dirt, grit, etc., cleaned out.

Two rolls of new packing should be applied as shown at *a* Fig. 4, and the remainder of the packing should be laid in crosswise, the ends being turned under so that strands of the waste will assist in keeping the packing in position against the motion of the journal. Care should be taken to have no loose ends which might work under the journal, or hang out of the cellar.

When additional lubricant is needed in the boxes it should be applied by the use of saturated dope.

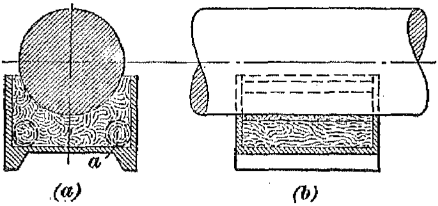


FIG. 4

In loosening up packing to avoid the hardened and glazed condition that results from too long a contact with the journal, section *b* of the packing should be loosened up first by pulling it forward from the sides and working it back under the journal at the center. If new packing is needed it should be worked back under the journal from the center, thus raising section *b* on the sides, care being taken that it is not lifted above the center line of the journal on either side.

### OVERHEATED JOURNALS AND CRANKPINS

**22. Causes and Remedies.**—Overheated journals and crankpins are a source of much trouble to the engineer, and he should endeavor to detect any signs of heating as soon as it develops for if discovered in time and properly treated it may be possible to prevent further heating or even have the parts run cool. Otherwise they may become so hot that the question of getting over the road will be a serious one and detention or an engine failure may result. On local runs, where there are a large number of stops, any sign of heating is apt to be detected by the engineer and he can inspect this part at each stop if necessary, and by this means prevent possible failure.

On fast trains, however, where long runs are made with but few stops, the chances of overheating are greater. In this case usually the first sign of some part warming up is when the enginemen smell the burning lubricant. When this is discovered, it should be attended to as soon as possible, and if considered necessary the speed should be slackened and extra stops made to treat it. If it is found to be very hot it may be necessary to obtain another engine.

Overheating is caused by any condition that prevents sufficient lubricant from reaching the bearing surfaces, or that prevents the lubricant from being distributed properly over these surfaces. Some of the causes of hot journals in engine and tender trucks, are insufficient or no lubrication; improper lubricant; badly fitted brasses which do not bear on the crown but pinch on the sides thus squeezing out and wiping off the oil film; dirt or grit getting on the bearing; the hub heating which drys out the packing next to the hub and causes the axle to heat at that point as well as farther in, thus drying out the rest of the packing and causing a hot box.

**23.** On trailing, and tender truck axles which have a collar on the ends, heating may be caused by the brass binding hard against the collar on the outside, or the shoulder on the inside, or both, due to the brass being too long overall, or too long from the lugs on the top to one of the ends. To prevent further heating from this cause the brass should be removed and the end or ends machined to ensure sufficient clearance so that when it expands under running heat it will not bind.

A bent axle will cause hot journals and should be removed and a new pair of wheels applied as soon as possible.

Worn out brasses, that is, brasses in which the bearing metal has been worn off, will result in overheating especially if the journals are heavily loaded, and new brasses should be applied at the first opportunity.

Improperly applied packing, too much, too little, or too poor a quality, as well as packing that has become glazed or soggy, will cause overheating. In cases of this kind the box should be repacked.

Defects in springs and spring rigging produce extra weight on the journals and causes them to heat. Overheating will also result if an axle is out of tram or if a wheel is out of quarter.

When the engineer discovers an engine, tender, or trailing truck journal heating he should, if possible, determine the cause, and if it is for want of lubrication he should supply more oil. If the fault is in the packing being glazed thereby acting as a wiper and keeping the journal free from oil, the glaze should be broken and properly saturated dope worked up against the journal. If the journal becomes so hot that the packing catches on fire, water should be used to put out the fire and cool the journal, then the old packing should be removed and new packing applied. If, after repacking, the journal still continues to heat, valve oil may be tried on it or the box packed with grease. If the journal will not run without further heating and it is piped so that water can be run on it, sufficient water should be turned on to keep it from getting dangerously hot and if possible the run either completed, or to a point where repairs can be made, or another engine obtained. On fast and important trains it may be necessary to apply water to the journals as soon as the heating develops in order to make time and prevent delays.

24. A defective tender-truck brass may be renewed by the engineer if it is practicable for him to do this work, and if one is available. Defects in engine and trailing truck boxes, broken or defective springs and gear and bent axles cannot be repaired by the engineer, but he should endeavor to make the journals run as cool as possible and report them for repairs at the end of run.

The driving boxes on the majority of locomotives are lubricated with grease which gives very satisfactory results. The grease in the cellars of the driving boxes is kept in contact with the axle by means of a spring or springs attached to a plate called the follower plate, upon which the grease rests. The springs press on the bottom of the cellar and a perforated plate bent to suit the axles rests on top of the grease

and comes between it and the axle. The perforations in the plate control the feed of the grease and prevent a too rapid consumption.

Two small rods called indicators, that have eyes in the lower ends, are attached to the follower plate and project through holes in the bottom of the cellar; they provide a means of holding the follower-plate springs compressed when applying new grease, and also indicate the amount of grease in the cellar.

Hot driving journals may be caused by the grease becoming depleted, by improperly fitted or defective perforated plates, follower plate or follower-plate springs; by the hub heating; or by defective or broken springs or spring rigging, thereby placing excessive weight on the journal.

**25.** If proper inspection is made of the cellar, heating should not occur from insufficient grease because the amount of grease in the cellar is easily ascertained by means of the indicators, and if found to be getting low the box should be reported to be repacked. Improperly fitted perforated plates that have ridges or dents, which wipe the grease from the axle and leave a part of it dry, will cause heating which will extend the full length of the journal. Holes in perforated plates filled up with foreign matter, such as carbon formed by the journal heating and burning the grease, will prevent it from reaching the journal and will cause heating. The plates should be removed and properly cleaned, and if dented or not fitting properly, they should be fitted to the axle. Hub heating will cause hot journals by melting away the grease next to the hub so that part of the axle gets no lubricant, thereby causing the axle to heat at that point as well as along the axle.

Defective engine springs, or spring rigging, such as broken springs or spring band shifted, broken hangers, or equilizers will cause the driving journals to heat. This is due to the weight being taken off some of the journals, and overloading the others.

When a driving journal heats with grease lubrication, additional grease should be applied by removing the end plate on the cellar, then by compressing the follower plate spring, the

grease can be inserted between the follower and the perforated plate. If the journal continues to heat, and becomes excessively hot, and the lubricant cannot be kept in the cellar but flows out as fast as it is put in, the journal may be relieved of some of its weight, provided that it is possible to run the wheel up on a wedge. Then by placing iron or hardwood blocks between the spring saddle and the frame, or between the equalizers and the frame and by keeping the cellar well packed, it should be possible to complete the trip.

On locomotives equipped with oil cellars, additional oil should be applied when heating starts to develop, then if the journal continues to heat, the cellar should be repacked.

Grease is used almost entirely in the lubrication of the crankpins. The grease is either inserted in a grease cup and compressed by a threaded plug so that it flows to the pin, or the grease is placed in the crankpins from the ends and is forced out through holes to the bearing surfaces when compressed by a plug threaded into the end of the pin.

**26.** The heating of the crankpins may be due to several causes. The brasses may be improperly fitted; the brasses may be so wide that they bind sideways between the hub of the wheel and the crankpin, cap or washer; the rod may have a bend or a twist and not line up properly, thereby causing the brass to bind on the hub, crankpin, or crankpin-washer. Dirt or foreign matter may get between the bearing surfaces; the lubricant may not get to the crankpin due to the brass shifting, so that the hole in the brass does not line up with the hole in the rod; the brass may become so loose in the rod that it will cause the grease to press out between the brass and the rod instead of flowing to the crankpin; or, the main rod brass may be keyed up too tight.

When the crankpins heat, extra lubrication should be applied, and if they continue to heat they should be reported. Extra attention should be given to rod brasses on rainy days or in sleet storms due to the lubricant being washed off the pins.

Hot bearings and pins in the valve gear may be caused by improperly fitted bushings, the parts of the gear may not be

lined up properly when assembled, and when sprung into place, they bind and heat. The oil holes may become stopped up due to the bushings shifting; foreign matter may get into the oil way; dirt or grit may work between the bearing surfaces, or sufficient oil may not be supplied.

The cause of heating should be ascertained and if possible removed. In the case of foreign matter in the oilway, the passage should be cleaned out. Additional lubrication should be applied to the parts, and if they still continue to run hot, they should be reported, so that the cause of heating can be determined and repairs made.

27. High compression in the cylinders will also cause the main crankpins to heat. For example, when drifting at high speed with the throttle cracked, and the reverse lever well hooked up, closure occurs earlier in the stroke than when the cutoff is longer. Therefore the compression is higher at short than at long cut-offs. The pressure against which the pistons are moving is communicated to the main crankpins and may be great enough to induce overheating. The remedy is to drift with the reverse lever farther down in the quadrant.

## CARBONIZATION IN CYLINDERS

28. **Cause of Carbonization.**—Carbonization in the majority of cases is caused by the hot smokebox gases, that are drawn into the cylinders, due to the vacuum formed therein, when an engine is drifting. The cinders, soot, and coke that are entrained and drawn in with the gases, adhere to the oil on the different parts in the cylinders and form a sticky deposit which the heat of the cylinder and the gases bake hard on to the surfaces. The admission of air into the cylinders will sometimes cause the oil to become ignited and form a carbon deposit.

29. **Effects of Carbonization.**—The carbon deposits build up in the packing ring grooves of the pistons and the valves, and cause the rings to stick and break, thereby producing blows. The hard carbon deposits also cause the packing rings, the valves, the pistons, and the valve and cylinder bushings to become worn through abrasion, which also causes blows, and

wastes fuel and water. The formation of carbon on the pistons and cylinder heads may cause pounds or broken heads. The carbon deposits also form on the edges of the ports and accumulate in the exhaust passages as well. The carbon on the steam edges of the ports, requires the reverse lever to be worked lower than otherwise, and the restriction in the exhaust passages will make a higher back pressure on the pistons. The result is an increase in fuel consumption and a reduction in locomotive efficiency.

**30. Prevention of Carbonization.**—The prevention of carbonization in cylinders is a difficult problem. Various methods are used to counteract this trouble, such as relief valves, by-pass valves, and drifting valves, with the idea of preventing the partial vacuum from being formed in cylinders. The use of relief valves and by-pass valves is being abandoned. The relief valve admits air to the steam chest, and hence to the cylinders during the period of admission, so as to prevent the formation of a partial vacuum. However, at short cut offs and high speeds, the relief valve will not open, due to the high compression that accumulates in the cylinder and that acts on the relief valve as soon as preadmission occurs. At longer cut-offs, the valve will open, but as air only passes to the cylinder during the period of admission, the air will reduce in pressure after cut-off occurs below the pressure of the atmosphere. Then at the point of release, smoke and gases, will be drawn in through the exhaust nozzle and exhaust passages from the smokebox.

By-pass valves are so constructed that the steam or the air in the cylinder passes back and forth through the valves from one end of the cylinder to the other, and it would therefore seem that a vacuum would be prevented. However, the ports and passages in the by-pass valves are generally too small to permit the air or the steam to pass through from one end of the cylinder to the other rapidly enough to do more than to reduce slightly the degree of vacuum. Also the air in passing through the small passages will become heated to such a degree as to affect the lubrication.

Drifting valves are usually so arranged that a jet of saturated steam is supplied automatically to the steam chest when the throttle is closed and the engine is drifting.

**31.** Probably the use of a cracked or partly closed throttle, and a cut-off of 25 or 30 per cent. is the best preventive of carbonization. The engineer should endeavor to keep enough steam flowing to the cylinders to prevent a vacuum from forming. When coming to a stop he should only partly close the throttle and it should be left in that position until the train is about stopped, then the throttle should be closed.

In the absence of a back pressure gauge it is harder for the engineer to determine the amount the throttle should be opened in order to prevent carbonization; generally the amount has to be greater with a short cut-off than is thought necessary. It has been found that if the steam pressure in the steam chest is less than about 75 pounds, the cylinder cocks are unseated by the pressure of the outside air, thereby indicating the presence of a partial vacuum in the cylinders. Therefore, the throttle opening should be such as to develop a steam pressure in excess of 75 pounds in the steam chest if carbonization is to be avoided. By using a longer cut-off, a pressure of 25 pounds in the steam chest will prevent a partial vacuum from forming in the cylinders. Some engineers judge that the throttle is opened sufficiently when the counterweight of the superheater damper lifts, but this indication is misleading because a lesser pressure than 75 pounds will cause the weight to lift.

**32.** The cylinder cocks may be used when drifting with a cracked throttle to determine if enough steam is entering the cylinders to prevent a vacuum from being formed and thus guard against the entry of smokebox gases that would destroy lubrication and cause carbonization. This may be done either by opening the cocks and observing that steam blows from them throughout the full stroke, or by leaving them shut and watching closely to see if a jet of steam comes from them at some part of the stroke. If there is not enough steam entering the cylinders to expand and follow the piston the length

of the stroke, a vacuum will be formed which will cause the cylinder-cock valves to unseat and allow air to enter the cylinder. However, before the valves seat again a small jet of steam will issue from them, thereby indicating that the throttle is not opened enough to hold the valve closed. If the engineer watches closely he can adjust his throttle correctly for drifting without moving the cylinder cock lever.

### STARTING THE TRAIN

**33. Operation of Throttle and Reverse Lever.**—When the train is ready and the conductor gives the signal to start, the engineer should answer the conductor's signal with two short blasts of the whistle in freight service or by ringing the bell in passenger service unless the rules specify otherwise. After giving the required signal, the engineer should place the reverse lever in full gear, not carelessly, a few notches from full gear, but into complete full gear so as to give the valves their maximum travel and thereby obtain the latest cut-off the valve gear is designed for. Where conditions permit, the cylinder cocks should also be opened to permit condensation to be worked out of the steam passages and the cylinders. The throttle should be opened gradually to prevent a violent jerk to the train, and also to prevent the drivers from slipping. The heavy exhausts, when the drivers slip, may tear and upset the fire and damage may also be caused to the running gear. With trains of ordinary weight, as soon as the driving wheels have made a few revolutions, and the train is started, the reverse lever should be pulled up several notches, and thereafter one notch at a time until the required cut-off is obtained. When starting a heavy train, the lever should be drawn up notch after notch until the proper working cut-off is found. Heavy trains can be accelerated or brought up to speed less rapidly than lighter trains, and this explains why the lever is hooked up one notch at a time with heavy trains instead of several notches at once as with lighter trains.

With the reverse lever operated as first described, it is remarkable how rapidly a locomotive will gain speed even with the lever hooked up quite high. More coal is wasted by work-

ing an engine too hard when accelerating than during any other period of locomotive operation.

34. The reason that the reverse lever is drawn back gradually after starting, is that less power is required to keep a train moving, than to start and accelerate it. The frictional resistance is greater at starting, hence a maximum cut-off is necessary. However, the train cannot be accelerated with a late cut-off because the large volume of steam cannot be exhausted fully from the cylinders as the speed increases, and this results in a high back pressure. It is also impracticable to design a locomotive boiler large enough to permit the use of late cut-offs without a decrease in steam pressure, except at low speeds. Moreover, late cut-offs are undesirable since they do not permit of effective expansion.

After starting the train some engineers open the throttle wide and leave the reverse lever in full gear with the impression that this method of operation will result in rapid acceleration. This is not correct because not only is acceleration retarded but holes are torn in the fire; the fire is pulled off the back grates up against the flue sheet, and clinkers are caused to form. This destroys the fire and as a result the steam pressure is greatly reduced

35. **Taking the Slack.**—If the train is very heavy and hard to start as in freight service, the slack should first be taken; that is, the cars should be bunched together so as to compress the springs and take up all the slack in the draft gears of the cars; then when the engine is started forward the cars are started one after the other. This method will enable an engine to start a train that could not be started otherwise. After bunching the slack, care must be taken not to open the throttle in such a way as to start the head end of the train too quickly, as this may break the train in two, damage draft gears and couplers, and cause delays. It is imperative that the slack of the entire train be taken up before starting forward, for if the slack is taken up in only a part of the train and the rear end is stretched, the train may be snapped in two as soon as the forward movement reaches the stretched portion. Slipping

the engine should be avoided, and if the train cannot be started otherwise, the rails may be sparingly sanded. Some engineers make a practice of bunching the train immediately after stopping; they are then ready to start when the signal is given. This practice is particularly good in cold weather when the train freezes up. By proceeding in this manner there is not so much danger of damaging the engine or breaking the train in two. As the train is slowly set in motion, the engineer and fireman should ascertain, by watching, whether any signal to stop is given from the rear end. The train should always be run slowly and carefully until all the switches, frogs and crossings of the yard are passed, and not until then and after the engineer has seen that everything is in order and the train is on the main track, should he increase the speed.

In starting passenger trains, it is necessary to get the train up to speed quickly, especially in local service when fast time must be made and stops are close together. It must be remembered, however, that it is not good policy to work an engine at a long cut-off in getting up to full speed. The best plan is to make time when the train is up to speed, and also in making the stops.

## PROPER OPERATION OF THROTTLE AND REVERSE LEVER WHEN RUNNING

**36.** It is well known that some engineers are able to handle trains on ruling grades or other difficult places and make time, while others with the same engine and loading will fail to do so even though they try hard. The most efficient engineer on any division is the one who uses the proper cut-off and the proper throttle opening, as it is their correct position that insures the ability to haul maximum tonnage over ruling grades and other critical points; makes higher speeds possible without waste of fuel; reduces the steam demands upon the boiler, under equal tonnage and speed conditions; and reduces by five to twenty-five per cent. the fuel used per unit of ton miles.

The following extract from the proceedings of the Master Mechanics' Association shows the importance of proper throt-

tle opening and cut-off: "Great accuracy in the selection of cut-off is more important at the highest speeds than at very low speed, since it is at the highest speed that the boiler is being taxed to produce the amount of steam necessary to provide sustained drawbar pull. A slight movement of the reverse lever either way in the short cut-offs, necessary with higher speeds, has a greater effect on the power of the engine than a similar movement from the full cut-off position at low speeds. Therefore, it is even more important that the precise cut-off be used at the higher speed than at lower speeds. For any given piston speed, there is an exact cut-off at which the highest power of the locomotive for that speed, will be developed. In other words, if any other cut-off than the correct one for the particular piston speed is used, whether it be higher or lower, less power will be delivered than the engine is capable of developing, and in most cases, steam, and therefore fuel will be wasted.

"When a longer cut-off than the correct one is used, the effect is greater back pressure, and steam is wasted because the net work performed by the engine is done by the difference between the pressure on the steam side and the pressure on the exhaust side of the piston, and any pressure on the exhaust side must be counterbalanced by increased steam pressure on the steam side which is a waste of steam.

"When the cut-off is shorter than the correct one for the particular piston speed at which the engine is running, the effect is again a loss of power because of the high compression that follows the earlier closure."

Under average conditions, the reverse lever should be carried in a position to give about a 25 per cent. cut-off, but under less favorable conditions of train, weather, or grade, the cut-off will have to be increased. A full throttle opening is usually recommended because the steam then absorbs more heat in passing through the superheater units, but good results are often obtained with a three-quarter opening or even less and a slightly longer cut-off.

With somewhat less than a full throttle opening, the lubrication is good and the friction of the valve is not excessive.

The highest speed is rarely, perhaps never attained when the throttle is wide open.

**37.** A back-pressure gauge is of great assistance to the engineer in selecting the throttle opening and cut-off that will give the best results These gauges may be either of the single or dupelx type; the former indicates the back pressure alone, the latter the back pressure and also the steam-chest pressure. In either case the back-pressure hand is usually piped to each of the four exhaust cavities in the steam chests. In freight service a maximum back pressure of about fourteen pounds and a minimum back pressure of about six pounds is usually specified and the throttle and reverse lever are operated accordingly.

Back pressure or the pressure exerted by the steam on one side of the piston subtracts an equal amount from the pressure that the steam is exerting on the other side of the piston to move it. The actual or effective pressure that moves the piston is then the *difference* between the two opposing pressures. Therefore, by keeping the back pressure within reasonable limits as indicated by a gauge increases the effective pressure and also the drawbar pull of the locomotive.

A heavy grade should be approached at the highest speed that the running conditions or the rules of the road will permit, and when on the grade the momentum should be maintained as long as it is possible to do so. When the speed begins to reduce, the reverse lever should be dropped a notch at a time as required, but the throttle should be opened wide first. The tendency is to increase the cut-off too rapidly either by dropping the lever from notch to notch too quickly or several notches at a time and this should be guarded against. A sudden increase in the length of the cutoff when the locomotive is working hard on a grade often has the effect of a more or less sudden loss of speed, due to the considerable increase in back pressure and consequent decrease in drawbar pull. The result is a decided loss in momentum which is so valuable and often the deciding factor in getting heavy loads over steep grades.

### FUEL ECONOMY

38. As the engineer is in charge of the engine the fireman should be governed by his instructions and they should cooperate in order to work the engine efficiently. The best of engineers cannot make a good showing with a fireman who does not fire the engine efficiently, that is, place the fuel in the firebox in such a manner as to evaporate into steam as much water as possible. The engineer also has his responsibilities with regard to fuel consumption and no fireman can make a good showing if the engineer does not cooperate with him in the proper handling of the reverse lever, throttle and injector.

The fuel bill is one of the largest items of expense to all railroads and economy is required in its use. The greatest portion of the fuel used on a railroad passes through the hands of the fireman and by using skill and good judgment, together with the cooperation of the engineer in the proper handling of the engine, the fireman can use the coal economically, or through inattention or lack of skill, he can waste it. By conserving coal and not burning any more than necessary, the work of firing is lightened.

The fireman should endeavor to carry as light a fire as possible consistent with the work required, maintain a uniform steam pressure at all times, and avoid unnecessary black smoke, and waste of steam through the safety valves by allowing the engine to pop.

The fireman cannot be expected to fire efficiently until he has thoroughly learned the road.

When an engineer has a new fireman, one who does not know the run, or who is not proficient, he should tell him what methods to use to get the best results.

### CAUSES FOR ENGINE NOT STEAMING

39. There are a great number of causes for engines not steaming, and engine failures sometimes occur that may be wrongfully charged up against the engineer's record. This is sometimes due to the fact that he often has absolutely no control over the condition of the parts that cause the trouble

on account of the practice of most roads pooling their engines. There may be defects in the boiler, flues, steam pipes, exhaust pipe, exhaust nozzle, etc., which it is impossible to detect until the engine is on the train. The fuel may also be of such poor quality that it is impossible to make steam.

Engineers with assigned locomotives are in a better position to prevent steam failures and they should endeavor to operate their locomotives so that a proper fire is carried to prevent the tubes and flues from leaking. When they detect any defects or parts that show the first signs of failure they can report them and have repairs made.

The exhaust steam in escaping through the stack tends to empty the smokebox of gases and produces a partial vacuum there, thus causing air to be drawn through the grates and in this way maintaining the draft through the fire. Anything that obstructs or cuts down the draft reduces the steaming capacity of the engine. For example, obstructed flues cut down the heating surface as well as the draft, and as a rule not only causes leaky flues and tubes, but increases the speed of the gases through the unobstructed tubes, and causes less heat to be absorbed by the water.

**40.** Air or steam leaks into the smokebox affect the steaming qualities of the locomotive by tending to reduce the vacuum, thus cutting down the draft on the fire. The air may be drawn in through leaks in the joints on the smokebox ring, the smokebox door, or around the steam pipe casing flanges, and between the cylinder saddle and the smokebox. Air leaks in the smokebox also cause the cinders in it to burn, often warping the smokebox front and door. Leaks into the smokebox may be detected by holding the flame of a torch near the point to be tested while the blower is on. The flame will then be drawn toward and into any leaky joint.

Steam leaks in the smokebox are caused by a defective joint or joints in the steam pipes, exhaust pipe, exhaust pipe nozzle, or the superheater header, or superheater units may crack or split or their joints may leak. Defective tubes or flues also cause steam blows in the front end.

A leak at the base of the exhaust pipe, due either to a defective joint or to the pipe being loose will also affect the steaming of the engine.

The exhaust pipe and nozzle, the smokestack or the smokestack extension set in such a manner that the exhaust jet is deflected from the center of the stack and impinges on one side will reduce the vacuum that should be developed in the smokebox, thus impairing the steaming qualities of the engine.

The diaphragm apron or damper if not properly set will cause a poor steaming engine by affecting the intensity of the draft through the fire. The damper governs the space through which the products of combustion have to pass to reach the smokebox, hence a higher adjustment of the damper lowers the pressure over the fire and increases the total draft, and a lower adjustment increases the pressure above the fire and lessens the draft. The damper is not a draft equalizing device.

**41.** The severe working of an engine with a light fire causes partially burned coal to be carried through the tubes and flues while in a sticky condition and by adhering to the netting, plugs up the meshes. The netting, when clogged, cuts down the draft and the steaming qualities of the locomotive. Other causes are irregular boiler feeding; insufficient ashpan opening; clogged grates, or clinkers in the fire which prevent sufficient air reaching the fire; too heavy firing, or too heavy in spots, causing clinkers to form; too light a fire, or the fire not level, being heavy in spots and lights in others. Working the locomotive too heavy for the fire, causes holes to be torn in it, and allows cold air to rush through, thereby lowering the temperature of the firebox and tubes. This makes a poor steaming engine and causes tubes and flues to leak which further cuts down the steaming qualities of the locomotive.

Honeycomb over the flue sheet or clogged flues prevent the passage of the hot gases through the flues and around the superheater units and results in a poor steaming engine and a reduction in the superheat.

An improper size of exhaust pipe nozzle, that is, one so large that there is not sufficient draft, or so small that holes are torn in

the fire, or an uneven exhaust due to derangements in the valve gear will greatly impair the steaming qualities of an engine.

Sometimes during roundhouse repairs, tubes of an improper size are applied to an injector, thereby preventing steaming by flooding the boiler.

### MAKING STOPS

**42.** When approaching stations where stops are to be made, the engineer should take into consideration the nature of the grades and other conditions when calculating on the stops, and the steam should be throttled down far enough from the station to permit the train to be brought to a standstill at the proper place by means of an ordinary application of the brakes. The practice of approaching stations at a high rate of speed and stopping at the right place by applying the brakes to their full capacity is a risky one. On some fast trains it may be necessary to run at high speed as close as possible to the station in order to make the time, but ordinarily this is not advisable as the engineer should have a certain margin to ensure safety should unforeseen conditions develop.

The whistle should be blown at the prescribed distance from the station, usually at the whistle-signal board, and when approaching grade crossings.

If the approach to the station is made through a town, the bell should be rung continuously to warn persons that may have occasion to cross the tracks that a train is approaching.

**43.** On runs where the time is fast and the stops are close together, advantage must be taken of every second in order to make the time; hence, an engineer should reduce as much as possible the time consumed in stopping and starting the train. In order to make time with a passenger train, the engineer should carefully study the conditions that govern the smooth handling of a train, and he should be able to judge the distance in which he can stop his train from different speeds and with any number of cars he is liable to have in ordinary passenger trains. As a rule an engineer has a landmark for easing off the throttle and this mark should be as close to the stopping point as he can make it, and still leave space enough

to stop the train smoothly. As it is much easier to make time when the train is up to speed than when accelerating, the speed should be kept up as long as possible. After starting the train the speed should be increased as rapidly as possible, but in doing so it is well to remember that time cannot be made by working the engine at a long cut-off. The reverse lever should always be drawn back soon after starting, say, after a few revolutions, and it should be continued to be drawn back as the speed increases. Conditions such as grades, the number of cars in the train, etc., govern the rapidity with which the reverse lever should be cut back.

Also, it is well to have a high steam pressure for starting, and an engine should have every advantage possible in starting a heavy train in order to keep up the steam pressure.

### HANDLING ENGINES IN COLD WEATHER

**44.** When handling an engine in cold weather certain precautions must be observed that are not necessary at other times. For instance, trouble may occur through injector pipes freezing. One injector is generally all that is used to feed the boiler with water, and in cold weather the pipes of the other injector will freeze very quickly if some means is not adopted to prevent them from doing so. It is necessary, therefore, to keep the steam circulating through the pipes during the time the injector is not working. This may be done by closing the overflow valve and opening the steam valve sufficiently to permit a small quantity of steam to blow back through the injector, feed pipe, and hose into the tank. Some engines are equipped with a cock located in the lowest part of the discharge pipe and called a frost cock. When opened this cock allows steam to flow through the discharge pipe and out to the atmosphere thus keeping the pipe from freezing up. As the leak of steam from this cock condenses and freezes, ice is formed on the parts immediately below it, very often on parts of the valve gear. In some cases a pipe is connected to the frost cock and led to a point near the ground to prevent the ice from forming on parts of the running gear, but the pipe is generally fairly long and of such a small diameter that the condensation

freezes in it and blocks the passage of the steam, often resulting in a frozen discharge pipe. On account of the ice forming on the locomotive and the frost-cock drain freezing up if it is used, a great number of engineers prefer not to use the frost cock but to operate the injector at frequent intervals, depending on the severity of the weather, in this way keeping the discharge pipe from freezing.

**45.** Care should be taken that too much steam is not forced into the tank because there is danger of getting the water too hot. In extremely cold weather, the suction pipes sometimes partly freeze, and thus deliver an insufficient supply of water to the boiler. In this case close the overflow valve and blow steam back through the supply pipe to thaw out the ice. The best way to use the lifting injector as a heater is to close the steam supply valve at the boiler almost entirely, pull the operating handle wide open, and close the overflow valve. When the engine is standing for any length of time, the cylinder cocks should be left open so as to drain the cylinders of condensation and prevent freezing.

If an engine equipped with steam heat is connected to a train without steam-heating apparatus, or is disconnected from a train entirely, a little steam should be constantly blown through the heating system to keep it from freezing.

The air-pump steam supply must never be shut off entirely for any great length of time, and the reservoirs, drain cups, and other parts of the air-brake apparatus in which water is liable to accumulate should be regularly drained. Also, where an electric headlight is used, a small quantity of steam must be allowed to pass through the turbine at all times during cold weather.

The drain cocks in the passages in the cylinder casting should also be opened after the engine has completed a trip in cold weather.

Sometimes in cold weather the valve gear is hard to move on account of the links and link blocks being covered with ice. Under such conditions the throttle may be opened with the reverse lever slightly out of mid gear either forward or back

and the engine may move in the opposite direction from that indicated by the lever. The reason for this action is as follows: If the reverse lever is just forward of the center, preadmission will occur at the front port on the right side when the piston is about two inches from the end of the stroke. The left crank is near the top quarter and the back port is closed. If the throttle valve is opened, steam will be admitted to the front of the right piston and as steam cannot get into the back end of the left cylinder the engine will move back until the back port opens on the left side. The engine will then move forwards and will sometimes stop again on account of the early preadmission and then move back. This is dangerous especially around cinder pits or roundhouses where men are getting under the engine, hence the reverse lever should always be placed far enough ahead or back to insure positive direction of motion.

### TAKING COAL AND WATER

**46.** The taking of coal and water is a matter that requires good judgment; it must not be taken more frequently than is necessary as extra coal and water will be used in again bringing the train up to speed, especially if the stop is on or near the foot of a grade. On the other hand it would not do to run short of coal or water before reaching the next coal chute or water tank. If possible water should be taken when making regular stops; on some runs it may be possible to take water at one of the regular stops even though the tank has considerable water in it at that time, but by taking water then, it will be possible to complete the run without making an extra stop, thus saving time by eliminating an extra stop later.

Where there are good and bad water tanks on a division an effort should be made to take all the water possible from the tanks that contain good water and as little as possible from those that contain bad water.

When taking coal at the coaling plants, the coal pile should be trimmed to prevent coal from falling off the tender while on the road, thus saving coal and preventing any possibility of danger to trackman or passing trains.

## THE USE OF CYLINDER COCKS

**47.** Cylinder cocks are used to drain the cylinders of any water that may have condensed in them or has been carried through from the steam chest or steam pipes. Water in the cylinders is liable to cause broken cylinders and cylinder heads. It also destroys lubrication and causes damage to pistons, valves, piston and valve packing rings, and piston rod, and valve stem packing.

The cylinder cocks should be opened at the engine house or terminal and left open for a short time after the throttle is opened to work out all condensation. If possible they should be opened when starting after stops of any length have been made.

When a locomotive foams and primes badly it may be necessary to open the cylinder cocks to prevent the water that is carried into the cylinders with the steam from damaging the cylinder heads, cylinders, or packing rings.

When leaving an engine standing that has a leaky throttle or dry pipe the cylinder cocks should be left open, and the reverse lever should be in the center to prevent any possibility of the engine starting through pressure building up in the cylinders.

## THE PROPER USE OF SAND

**48.** Considering the size of the modern locomotive and the trains handled, a dependable flow of sand is essential to safety and satisfactory performance, as it is general practice to haul all tonnage possible consistent with speed and safety.

The engineer has to use good judgment in the use of the sand in order to get his train over the road without delays or damage to equipment. Before leaving the roundhouse he should see that the sand box is full of sharp, clean sand and that the sanding device whether operated by air or lever, is in proper working order, that the sand pipes lead fair and close over the rail and as close to the wheel as possible.

In the most of cases a locomotive will start and accelerate the train without sand, and no fixed rule can be given for its use, as the condition of the rails; weight of the train; location

of train when starting; on a grade, curve, or curves; near or on a grade crossing; or passing over frogs or switches, must be taken into consideration by the engineer, and he has to govern himself accordingly and use his judgment.

If sand is used it should be used as sparingly as possible, only enough being used to give the drivers grip. As soon as the train is in motion and the locomotive will pull it without slipping, the use of the sand should be discontinued.

Sand increases the grip of the drivers on the rail, but it also increases the rolling friction, and makes the train pull harder than on a bare rail. When more sand is used than is necessary, there will be a greater retarding effect and heavy trains are often stalled on grades due to the use of too much sand.

When a locomotive with a heavy train is climbing a grade it is very important that slipping be prevented, especially when the engine is working hard at a slow speed. To slip at such time may stall the train because the speed will drop so quickly that by the time the drivers catch the rail again, the locomotive may not have sufficient power to keep the train moving. Slipping at such times is also very hard on the draft gear, and the running gear of the engine.

**49.** In the event of an engine slipping, sand should never be dropped on the rail until the throttle has been closed enough to stop the slipping as otherwise serious damage may result, such as the breaking of crank pins, rods, etc. The throttle should be closed, the sander operated, then the throttle should be opened again. Particular attention should be taken to see that the sand is operating on both sides of the engine and not on one side only and that both of the pipes lead the sand fairly on to the rail so that it flows on both rails at the same time. When used on one side only, the axles are subjected to a twisting strain that may result in bent or broken axles, main or side rods, or crank pins.

On foggy days, during a light shower, or with mist or frost on the rail or when the rail is slippery from some other cause, it is good practice to drop a little sand on the rail frequently enough to keep the tires dry and thus prevent slipping.

The use of sand also prevents the flattening of tires by assisting adhesion in stopping trains when conditions are such that they would otherwise slide by the points where it was desired to stop. Sand may also be applied to assist in making emergency stops.

Thick sanding besides retarding the train is apt to cause hot bearings by the sand working into them, and also causes wear in guides and crossheads. The most important thing to remember in connection with this subject, however, is to use good judgment in the amount of sand used and the condition under which it is used, so that the train will not be retarded any more than is absolutely necessary.

### USE OF BLOWER

**50.** The blower consists of a steam pipe connected at one end to the steam turret and the other end so arranged in the smokebox that when the blower valve is opened a jet or jets of steam are directed up the stack thereby creating a partial vacuum in the smokebox that results in air being drawn through the fire. It is used when building up the fire at the roundhouse or while standing on the road, and while standing at stations, to prevent black smoke. When an engine on a passenger train is stopping at a station, it is good practice to put on the blower just before the throttle is cracked in order to prevent a great volume of black smoke appearing. It is also beneficial to open the fire door.

The blower is also used when cleaning or drawing the fire to keep the cab clear of smoke, flame, dust and ashes. The blower should be used as lightly as possible at all times, especially when cleaning or drawing fires and when the fire is thin, as the excessive amount of cold air drawn into firebox will cause leaks in the tubes, flues and firebox.

The blower is also used when drifting or running with a light throttle on passenger trains to lift the smoke.

### PROCEDURE IN EVENT OF LOW WATER

**51.** When through carelessness in the operation of the injectors or feedwater pump or through their failure to deliver water to the boiler, the water becomes so low that it cannot be seen in the water gauge or water column, or does not show when the bottom gauge cock is opened, an overheated crown sheet or possibly a boiler explosion may result if precautions are not taken to prevent such an occurrence.

If the water has been allowed to get low through carelessness, the engineer should endeavor to locate the water level by closing the top water-gauge cock and opening the throttle if engine is standing, then if the water appears in the glass or at the bottom gauge cock he should apply the injector or feedwater pump in order to raise the water level. If the water does not show in the glass or at the bottom gauge cock, or if the feedwater pump or injectors are defective he should immediately draw the fire by shaking a section of the grates at a time so that as soon as the first section is clear a large amount of cold air will rush in to lower the temperature of the boiler. After drawing the fire, if the weather is cold, the tender hose should be disconnected and the tank drained. The air reservoir, air pump, feedwater pump, and all piping should be drained of all water; the boiler also should be drained as soon as the pressure and temperature of the water has dropped enough to allow this to be safely done so as to prevent any damage by freezing.

### PRIMING: CAUSES AND REMEDY

**52.** Priming is the act of carrying water in the form of a spray from the boiler into the steam chests and cylinders.

The principal causes of priming are as follows: Carrying the water too high thus reducing the steam space, the boiler improperly designed, that is lacking in steam space so that it has to be forced beyond its capacity; the use of dirty water which forms a scum on the surface; a sudden reduction of the pressure caused by opening the throttle quickly or by the safety valves blowing off.

The heat transmitted through the walls of the firebox and tubes causes the water at these points to be hotter than at other parts of the boiler. The steam that is generated near these surfaces, rises to the surface of the water in the form of little bubbles which are prevented from expanding by the pressure of the water. As the bubbles near the surface, the water exerts less pressure on them and they explode and throw small particles of water into the steam space in the form of spray. With a high water level, more or less water will then be carried through the throttle valve with the steam.

**53.** With engines using saturated steam, priming is apt to cause broken cylinders or cylinder heads, as it washes out the lubricant and causes cut pistons and valves, and destroys the valve stem and piston packing.

To prevent damage in priming with excessive water, the cylinder cocks should be opened and the supply of feedwater cut off until the water level drops to the correct height in the boiler. The blow-off cocks may be used to lower the level of the water and the throttle should be eased off until the correct level has been reached.

Priming is detected by the appearance of spray at the stack, and can also be detected by the sound of the exhaust.

With superheaters, the water that is carried over with the steam is converted into steam in the superheater units, thereby lessening the degree of superheat and increases the condensation of steam in the cylinders. The entry of water into the superheater units, will in time cause them to burn out. Any foreign matter in the water will be deposited in the units, and this will continue until the surface of the unit is covered over. The greatest accumulation is usually at the return bends at the back end of the units, due to these portions being nearest the firebox where the rate of evaporation is greatest. With the steam no longer in contact with the inside surfaces of the units, the firebox ends of the units will eventually become burned until finally they are no longer able to withstand the steam pressure.

## FOAMING

**54. Theory of Foaming.**—When the generation of steam is accompanied by the formation of a mass of foam or bubbles on the surface of the water, the water is said to be foaming. The theory of foaming is as follows: When water is boiling, a thin film of liquid known as a steam bubble encloses each particle of steam until it reaches the surface of the water. Under normal conditions, the bubble then bursts and sets the steam particle free. However, with certain impurities in the water, the thin film of liquid around the steam bubbles has greater tension and does not rupture so readily so that the steam bubbles on rising to the surface do not burst but persist as a mass of bubbles or foam on top of the water. The mass of steam bubbles or foam builds up to such an extent that it passes through the throttle valve. A considerable amount of water is then carried into the superheater units and results in the objectionable features that follow the use of wet steam. Foaming is usually caused by a heavy accumulation of soluble alkali salts combined with mud and other matter in suspension such as loosened scale.

**55. Procedure When Foaming Occurs.**—Foaming occurs more readily when the water level is high than when low. The reason is that the steam space is less with high water, and when the throttle is opened, the steam pressure is drawn down more quickly, which causes the steam to be generated faster, thereby aggravating foaming. With a lower water level and hence with a greater steam space, the pressure is not affected to such an extent when the throttle is opened and the tendency to foam is lessened. Therefore, it is the practice to carry the water level quite low with water that foams. However, the impurities may be present in such quantities that foaming will be more or less continuous regardless of the water level. Foaming can be controlled to some extent by means of the blow-off cocks and blowing out should be started at the beginning of the trip because a large percentage of the solids in the water have already been precipitated as sludge before the engine is moved.

A boiler free from sludge is not so liable to foam, because when sludge is present, any rough handling or unusual hard work will cause it to rise and mix with the water and result in foaming. The amount of water to be blown out will be much less if the blowing out is started early than if no water is blown out until foaming actually begins. The blow-off cocks should be operated as already explained.

At the first indication of foaming, the throttle should be partly closed and if necessary the cut-off should be lengthened.

Many railroad companies in bad water districts make a practice of treating the water to prevent foaming.

With enginemen accustomed to bad water conditions there is practically no danger of burning the boiler in cases of foaming. Foaming is objectionable because it gives wet steam, and also because the impurities in the water are deposited in the superheater units and causes them to overheat.

### CAUSES FOR UNEVEN EXHAUSTS

**56.** When the exhausts are of unequal intensity or do not occur at regular intervals the engine is said to be lame. Generally this condition is due to the valves not being properly set, to a derangement of the valve gear caused by wear or springing of the parts, or to leaky valve or piston rings. The derangement or leak has to be considerable before the exhausts are affected enough for the engine to sound lame.

If the valves are not properly lubricated and become dry, the engine may sound lame especially when the parts of the valve gear are of light construction because they will spring enough to make the exhausts sound uneven. This trouble is generally overcome by increasing the supply of valve oil.

An engine with a valve gear of light construction may sound lame if when starting a train the reverse lever is hooked up too quickly, but the trouble can be corrected by dropping the lever or partly closing the throttle.

If the valve on one side is not properly set, or if the parts of one gear are worn or deranged in any way, and the valve on the other side is square the result will be either a heavy and a light exhaust, two heavy exhausts, or two light exhausts

on that side. The intensity of the exhausts will be as follows: — —— — –; — —— — ——; — – — –; unequal length designating uneven exhausts, and the lines of the same length, normal exhausts.

The side at fault can be located by a study of Fig. 5, which shows the positions of the crankpins on the right and left sides when the exhausts occur at the various ports with the engine running forward. Thus if the uneven exhausts occur when the right crankpin is somewhere between 1 and 2 and 3 and 4, the trouble is with the valve gear on the left side. If the left

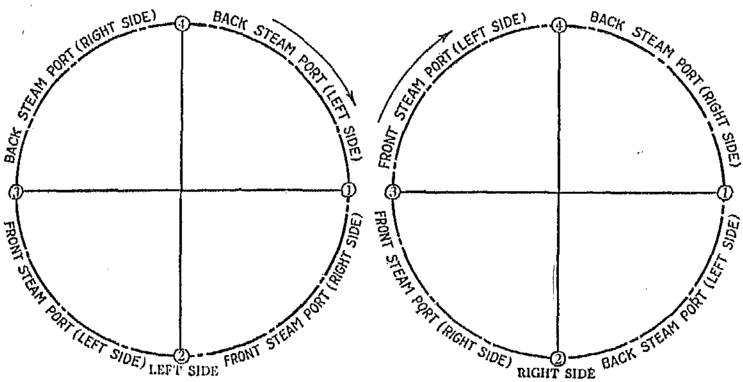


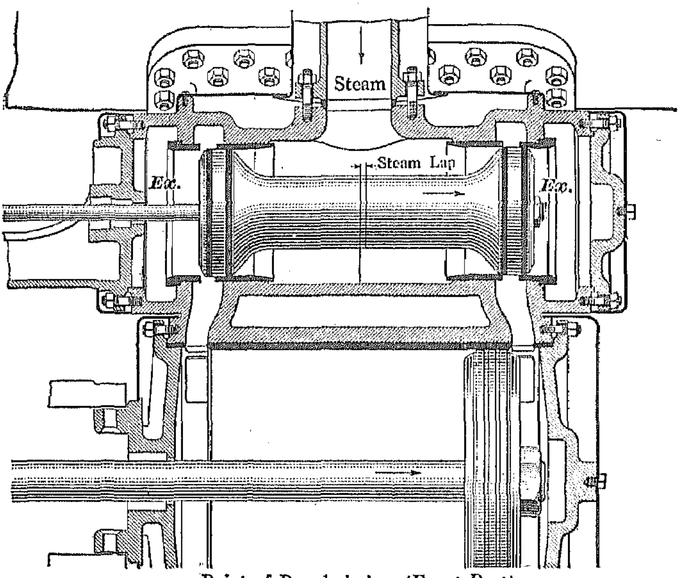

FIG. 5

side was being watched, and this valve gear was out, the uneven exhausts would occur between 4 and 1 and 2 and 3. If the right valve gear is out, and this side was being watched, the uneven exhausts would occur between 4 and 1, and 2 and 3.

A leaky or broken exhaust ring on a valve will cause one light exhaust and the exhausts will then sound as follows: — — — –; or three normal and one light. A leaky or broken steam ring will cause one heavy exhaust, and the intensity of the exhausts will then be — — — ——; or three normal and one heavy. Piston rings that blow on both strokes cause two light exhausts, thus — – — –. The engine must be moving at low speed in order to notice the difference in the intensity of the exhausts.

## BLOWS

**57. Effect of Leaks.**—Leaky steam and exhaust rings on the valve and leaky piston rings are not only wasteful of steam but they reduce the power of the locomotive and prevent it from working smoothly and efficiently. Leaky rings, particularly the valve rings, make it difficult or impossible to lubricate properly the valves and the cylinders. The fact that no audible blows exist is no indication that the valve rings and the

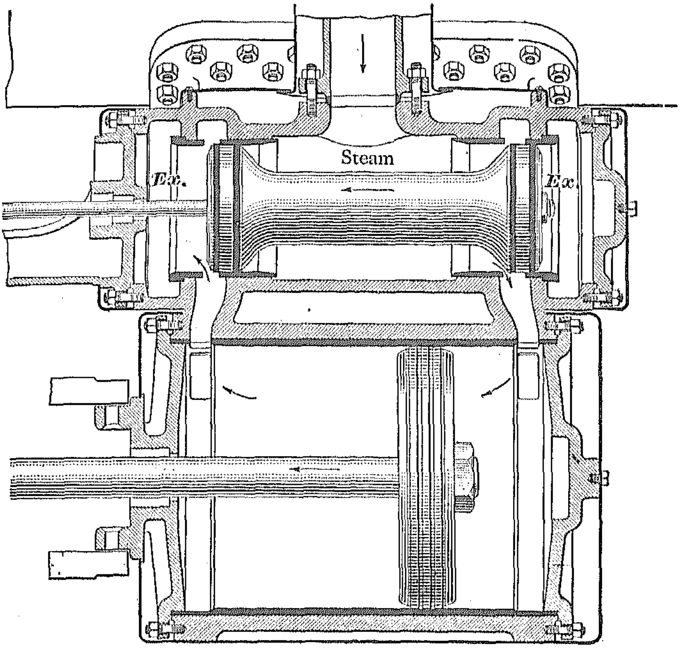



**Point of Preadmission** ***(Front Port)***

FIG. 6

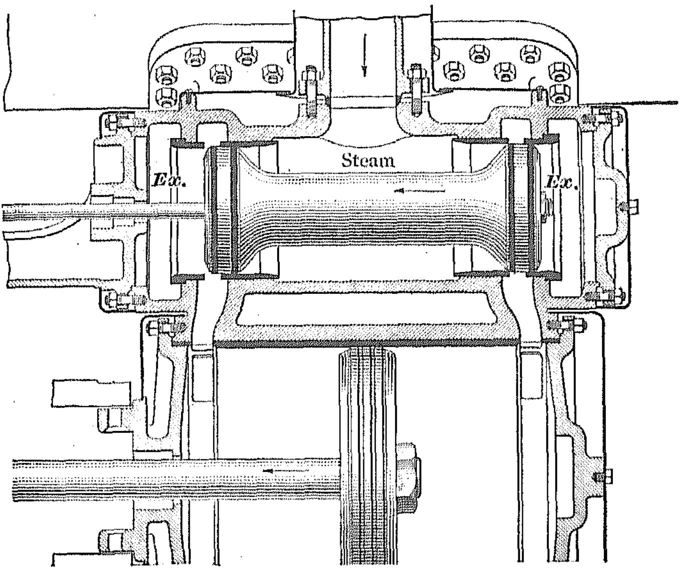
piston rings are tight. The leaks may be great enough to impair the power of the locomotive and still may not be audible, in fact with superheated locomotives, the first indication of leaks is not a blow but instead a noticeable loss of power.

**58. Purpose of Rings.**—Leaky steam and exhaust rings can be located with much more certainty if one has an understanding of the purpose of the rings. In brief the purpose of the steam and the exhaust rings is to form a partition (1)




Port Opening

FIG. 7



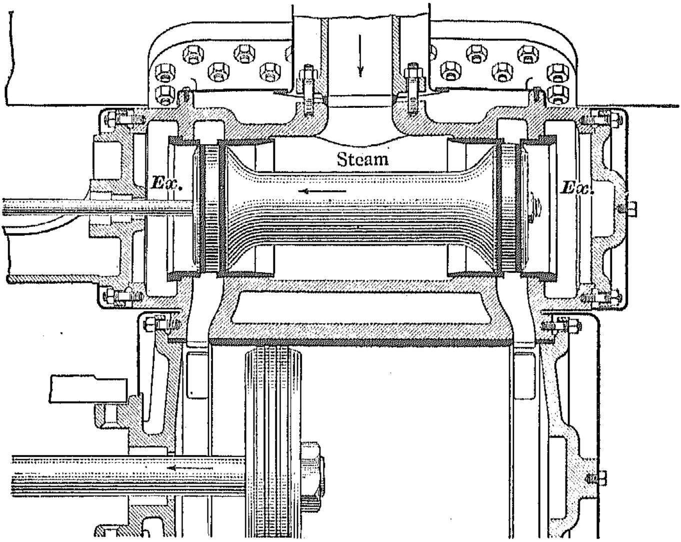

Cut-Off *(Front Port)*

FIG. 8

between the steam chest and the atmosphere; (2) between the steam chest and the cylinder, and (3) between the cylinder and the atmosphere.

As shown in Figs. 6, 7, and 8, the front exhaust ring of an inside admission valve forms a dividing line between the steam chest and the atmosphere between the point of preadmission and the point of cut-off, or during the period of admission. If the ring is not steam tight, the pressure is lowered in both the steam chest and the cylinder, thereby resulting in a greater tax on the boiler.

The front exhaust ring also separates the cylinder from the atmosphere between the point of cut-off, in Fig. 8 and the




Release *(Front Port)*

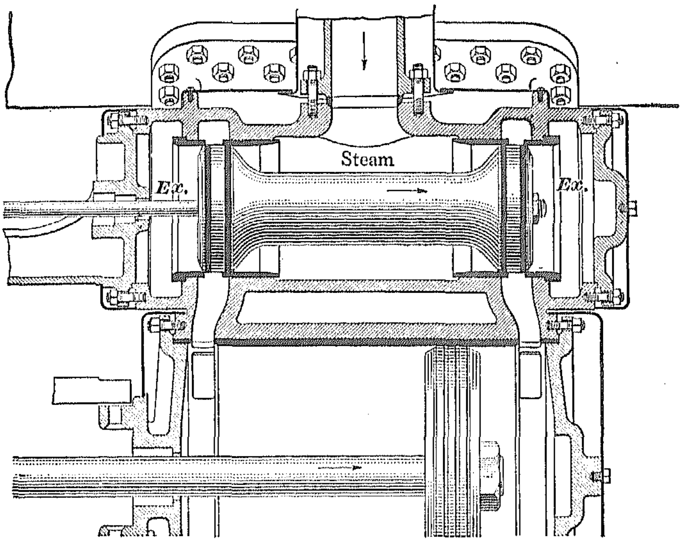
Fig. 9

point of release, in Fig. 9 or during the expansion period, and this results in a loss of cylinder pressure if the ring leaks.

The front exhaust ring shown in Fig. 10, separates the cylinder from the atmosphere between the point of closure, and the point of preadmission in Fig. 6, and thereby prevents the

building up of compression if the ring is not tight. This further taxes the boiler for the steam required to fill the cylinder clearance before the piston starts in the other direction.

The back exhaust ring performs similar functions at the other end of the valve.




Closure *(Front Port)*

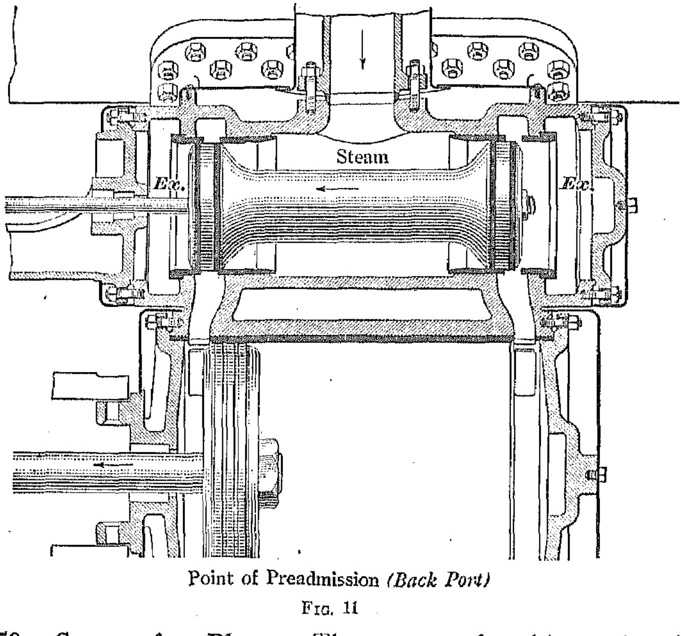
FIG. 10

The front steam ring of an inside admission valve forms a dividing line between the steam chest and the cylinder between the point of cut-off as shown in Fig. 8, and the point of release in Fig. 9, or during the expansion period. If the ring leaks, steam will continue to pass to the cylinder after cut-off occurs, thereby giving an excessive volume of steam in the cylinder as well as an uneven turning impulse on the wheel.

The front steam ring also separates the steam chest from the cylinder between the point of closure, as in Fig. 10 and the point of preadmission in Fig. 6, or during the period of compression, and the result, if leaking, will be excessive compression and a retarding effect upon the piston.

In addition the front steam ring separates the steam chest from the atmosphere during a part of the first exhaust period, as shown in Fig. 11, and the ring if leaking, tends to lower the steam chest pressure and prevents a normal exhaust. The back steam ring performs similar functions at the back end of the valve.

Piston rings at all times partition the steam side of the piston from the exhaust side, and if the rings are leaking, they will affect more or less seriously the power of the locomotive.




Point of Preadmission *(Back Port)*

FIG. 11

**59. Causes for Blows.**—The causes for blows in the valves may be due to improperly fitted, worn or broken rings; the ring grooves may be carbonized, which will cause the rings to stick and not expand against the walls of the valve bushing; the valve bushings may be worn or cut, or the nuts on the valve stem may be loose, which permits the steam to leak through the joints between the valve body and the follower.

Blows in the cylinder may be caused by improperly fitted piston rings; the rings may be worn, broken, or carbonized in

the piston grooves so that they cannot expand and press against the walls of the cylinder; or, the piston may be worn smaller than the cylinder so that the rings cannot make a proper joint.

The rings in the valve and piston will also wear out or break more frequently than otherwise if the locomotive is allowed to drift with the throttle closed This permits smoke and foreign matter to be drawn into the steam chests and cylinders, which destroys the lubrication, and cuts the surfaces of the valves, pistons, rings and bushings. The effect is the same if the engine is allowed to prime.

In some cases, through a desire to make a good showing in the economy of valve oil, the supply is cut down to such an extent as to make it impossible to run the engine without damage to the valves, valve rings, valve bushings, cylinders, pistons and piston rings.

## TESTING FOR DEFECTIVE VALVE AND PISTON RINGS

60. **General Instructions.**—It is difficult, if not impossible, to lay down a set of positive tests for the location of defective rings in the valves and pistons. A defective ring on a valve is not difficult to locate, but if both valves have defective rings, the question of making an accurate test becomes more complicated. The better knowledge the engineer has of the position of the valve rings in relation to the ports for the different positions of the crankpins, the easier it will be for him to make an accurate test under any condition. There should never be any difficulty in the location of defective piston rings, but considerable doubt may exist as to the location of defective valve rings. The important thing to locate is the valve with the defective rings rather than the exact location of the bad ring. To specify any particular ring as defective is of no service because the valve has to be pulled in any event. When the machinist pulls the valve and examines the rings he should note whether they have been bearing against the valve bushings all around. If the face of any of the rings shows black in spots, it indicates blows, and the ring should be removed.

When making the tests, any passage of steam through the exhaust passages from one side of the engine to the other will

be disregarded. With a single exhaust nozzle, the exhaust passage from each cylinder join below the nozzle tip, but should the steam leak from one side while the other is being tested, it can pass out the nozzle with less restriction than it can pass to the side under test.

**61. Testing Piston Rings.**—The piston rings should be tested first when making a test for blows. To make the test, place the engine on either quarter, assume the bottom quarter

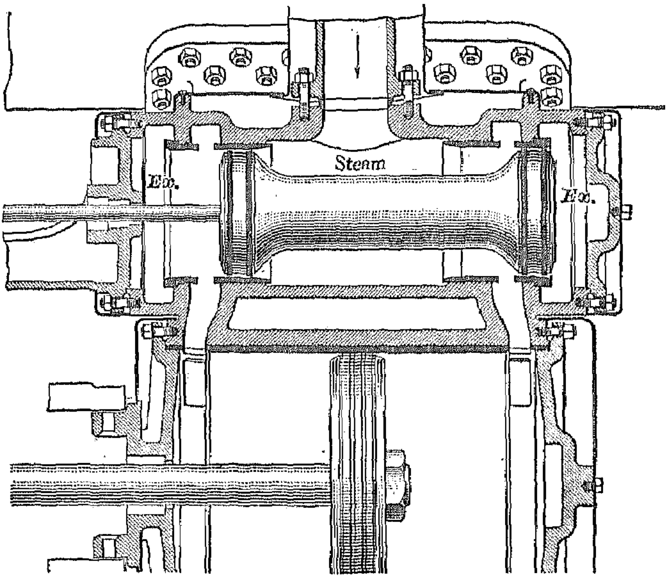



FIG. 12

in this instance, and move the lever all the way forward. The piston and the valve will now be in the position shown in Fig. 12. Then set the brakes, open the cylinder cocks, and partly open the throttle. If the piston rings leak, a blow of steam will occur at the back cylinder cock. Next move the lever to full back gear, and the valve will be at the position shown in Fig. 13. If steam appears at the front cylinder cock, it is a further test that the piston rings are leaking. Defective valve rings will not interfere with this test unless they all leak on the valve on this side, which is improbable.

Therefore, this test for leaky piston rings may be considered as being fairly positive.

Before making this test, shut off the compressor, if its exhaust is piped to the exhaust passages, also shut off the lubricator as well as the steam valves of all auxiliary devices that are connected with the cylinders.

Sometimes the bull ring of a built-up piston is such a close fit that it will prevent the escape of steam from one end of

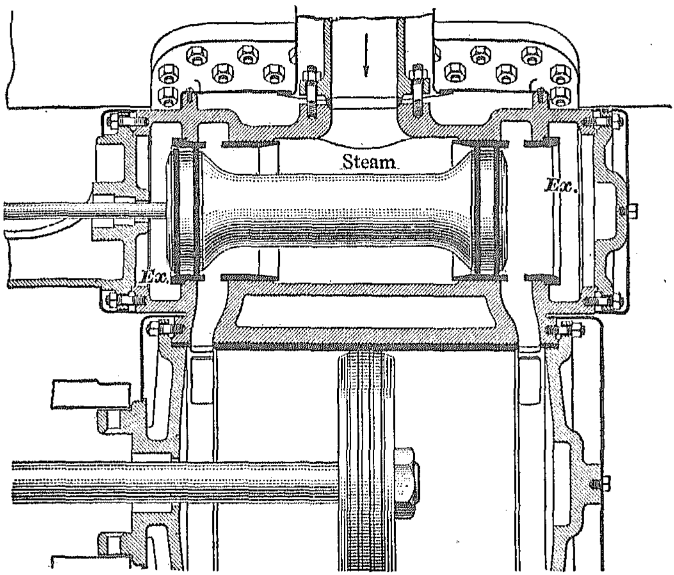



FIG. 13

the cylinder to the other after the piston has been heated up even though the rings are defective. Such a condition causes an intermittent blow or the blow will occur at starting when the cylinder temperature is low.

**62. Testing Steam Rings.**—When testing the steam rings, place the valve to be tested as nearly as possible in a central position, in the following manner: Move the engine until the crosshead is in the center of the guides as nearly as can be judged, and with the Walschaert valve gear, place the link block pin opposite the link trunnions by moving the reverse

lever towards the center. More attention should be given to the position of the link block pin than to the position of the lever in the quadrant, because the reach rod may be too long or too short. With the Stephenson gear, plumb the rocker arm, and with the Baker gear, plumb the vertical arm of the bell crank. By these methods, the valve will be more accurately centered than by attempting to spot the crankpin on the quarter.

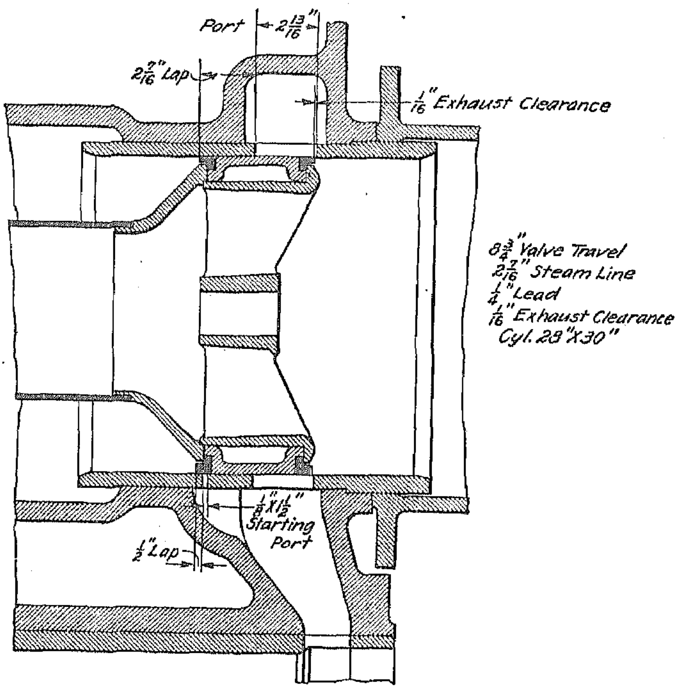



Fig. 14

The accurate spotting of the locomotive is particularly important when testing the steam rings of the valves of limited cutoff locomotives. As shown in Fig. 14 each steam ring with the valve exactly central overlaps the starting ports by only one-half inch. If the locomotive is not spotted accurately or if there is lost motion in the valve gear, the valve may not cover a starting port, thereby giving the effect of a leaky steam ring. It will be assumed when centering the crosshead, that the

crankpin has been placed near the bottom quarter. If the proper care has been taken, the valve will now stand central as shown in Fig. 15 with the steam rings forming a partition between the steam chest and the cylinder. If the rings are tight, steam cannot enter either end of the cylinder, when the throttle is opened, and the appearance of steam at either cylinder cock is an indication that the steam ring on that end of the valve is leaking. However, it sometimes happens that the

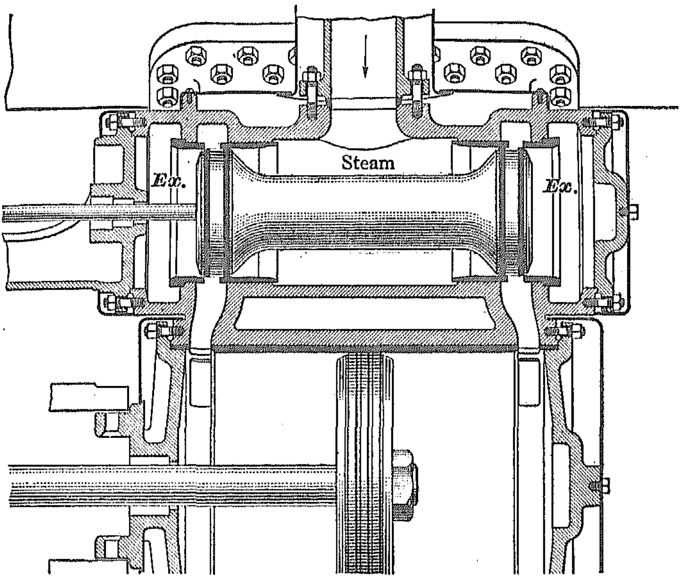



FIG. 15

valve bushing does not make a steam-tight joint in the cylinder casting, and steam will blow between the bushing and the casting from the steam chest into one end of the cylinder in all positions of the valve. Also the surface of the valve bushing that forms the valve seat may be badly worn or scored and will produce the same effect. Assuming the blow to be at the back cylinder cock, then the difference between a blow at the back steam ring and at the valve bushing is that the former can usually be entirely stopped or reduced in volume by moving the lever to full forward gear because this moves the valve until the

back exhaust ring, as shown in Fig. 12, makes the joint. If the blow continues either the bushing or both rings on the back end of the valve are defective. Steam will discharge from the front cylinder cock when making this test because the valve has the front steam port open.

To test between a defective front steam ring or front bushing, place the reverse lever in full back gear and note the indications as just explained.

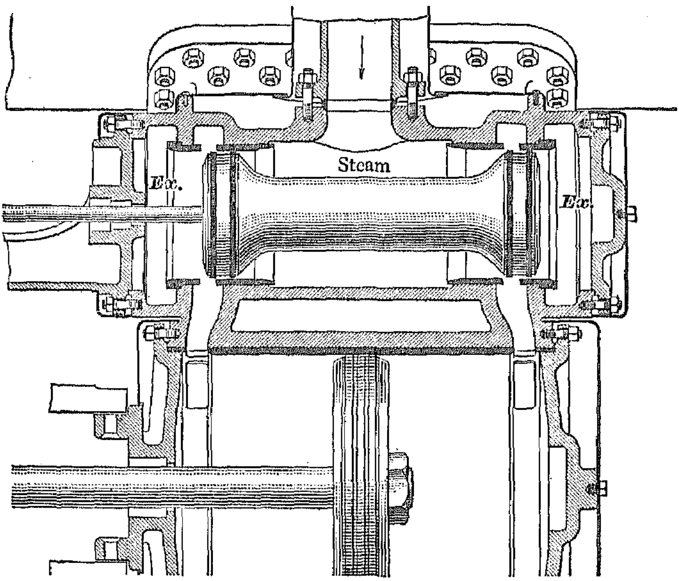



FIG. 16

**63. Testing Exhaust Rings.**—There are several good tests for leaky exhaust rings. One of these tests is made as follows: With the engine in the same position as when testing the steam rings, move the reverse lever forwards until steam appears at the front cylinder cock. The front exhaust ring, shown in Fig. 16, is now a partition between the steam chest and the atmosphere, and if it leaks, a blow will be heard at the stack. Next move the lever to full forward gear, as in Fig. 12, the front steam ring now becomes a partition between the steam chest and the atmosphere and the blow will stop if the

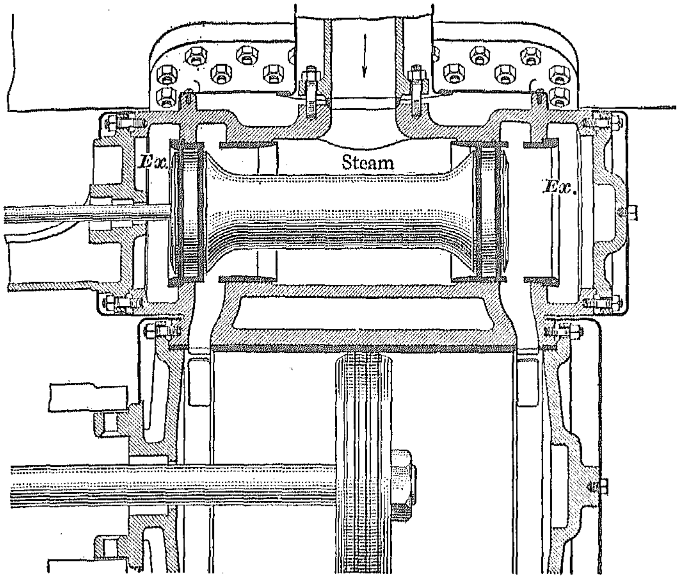
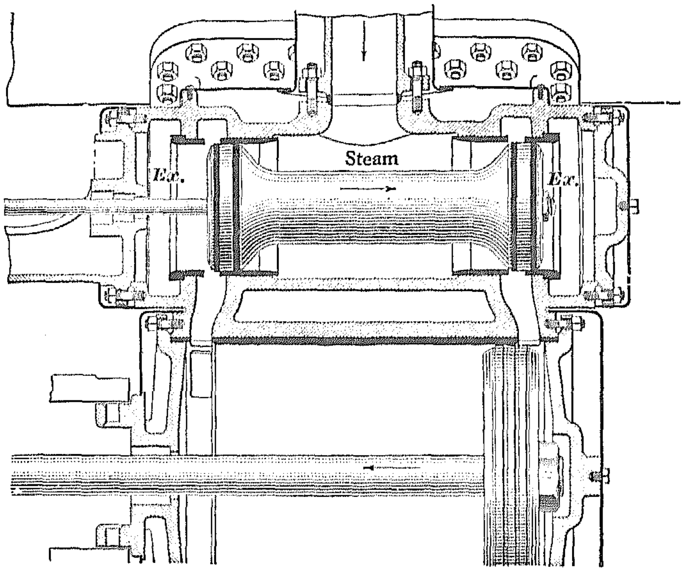



Fig. 17




Lead *(Front Port)*

Fig. 18

steam ring is tight. To test the back exhaust ring, first move the reverse lever backwards, (see Fig. 17) and then proceed as just explained.

Another test for exhaust rings is to move the crosshead to the front end of the stroke. The front steam port is now open the lead, Fig. 18, and the front exhaust ring is a partition between the steam chest and the atmosphere. If the ring leaks, a blow will be heard at the stack. Next move the engine

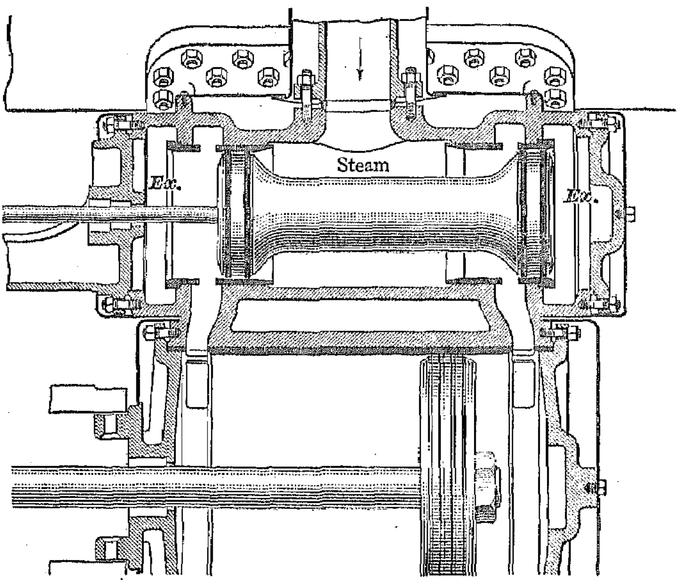



Fig. 19

until the crankpin comes to the bottom forward eight, then with the reverse lever in full gear, the steam ring will have passed over the exhaust edge of the port, Fig. 19, and the blow will stop if the steam ring is tight.

To test the back exhaust ring, move the crosshead to the back end of the stroke, and next move the crankpin to the top back eight.

Another test for a leaky exhaust ring is to watch the stack closely when moving slowly or when starting a heavy train. A leaky ring will cause a noticeable whiff of steam at the stack

just before the exhaust occurs from the end of the cylinder where the ring is located, the same as if the blower had been opened and closed quickly.

64. **Running Test For Valve Rings.**—A steam ring that leaks to any great extent will cause one heavy exhaust in each four, and a leaky exhaust ring will cause one light exhaust in each four. The difference in the intensity of the exhausts will be more noticeable at low speeds with the engine working at a long cut-off. The valve with the defective ring can be located from a study of Fig. 5. A heavy or a light exhaust with the engine moving forwards, and with the right crankpin between 1 and 2 or 3 and 4 indicates that the defective ring is on the left valve. If it occurs between 2 and 3 or 4 and 1 the defective ring is on the right valve.

When testing the valve and piston packing rings of three-cylinder locomotives, each cylinder should be tested separately in the same manner as explained for a two-cylinder locomotive.

## POUNDS

65. **Causes for Pounds.**—A pound is not only destructive to the engine but it is a source of annoyance to the engineer. When a pound develops, the engineer should endeavor to detect the cause and have it remedied as soon as possible, because if permitted to continue, more serious trouble may result. Pounds in the driving boxes and in the rods are liable to cause frame breakage and damage to the running gear.

Pounds in the main rods and side rods are caused by improperly fitted or worn brasses, which being larger in diameter than their pins, result in a pound when the slack is taken up at each end of the piston stroke. Worn side-rod brasses permits the rods to rattle on the crankpins when drifting with a closed throttle. Worn or loose knuckle pins will also cause a pound in the side rods.

Pounds in the crown brass of a driving box are caused by the thrust and pull action of the piston. This action wears the brass faster on the front and back, than on the crown, which allows the axle to work back and forth in the brass and produces a pound every time the stroke of the piston is reversed.

Excessive pressure is sometimes used when pressing the crown brass into a driving box and this causes the box to open out at the bottom so that the shoe and wedge faces are not parallel. With the box wider at the bottom than at the top, the wedge when set up will be tight at the bottom of the box and loose at the top. This condition allows the box to move back and forth at the top every time the piston stroke is reversed, and causes a pound.

If the oil or grease cellars are not fitted properly to the driving box, but are a loose fit, the box will often close in at the bottom as the crown brass becomes worn, and a pound will result.

**66.** Loose or broken crown brasses, slack wedges, or loose pedestal binders will also cause pounds. Loose or improperly fitted pedestal binders cause a pound by permitting the ends of the pedestals to work in the slots in the binders, and may cause a crack in the frame near the junction of the pedestals with the top rail.

A loose wristpin in the crosshead; a piston rod loose in the crosshead; or a piston loose on the rod, will cause a pound.

Pounds in the cylinders are often caused by the front end of the piston rod or piston striking the cylinder head, because of the main rod being too long; or if it is too short, the piston will strike the back cylinder head.

The repeated setting up of the wedges causes the axles to move closer to the cylinders, and the pistons to move closer to the front cylinder heads. This in combination with worn bearings may reduce the clearance enough to cause a pound.

A cylinder loose on the frame due to loose bolts or cylinder keys will cause a bad pound and it should be keyed up and rebolted at the first opportunity.

A broken frame always causes a bad pound, and the engineer should examine the break as the location may be such as to make it necessary to give up the train at the nearest station.

Pounds may be caused by flat spots on the tires made either by skidding the wheels or by high compression in the cylinders due to some derangement of the valve gear.

67. **Tests for Pounds.**—To test for all pounds in the rods and the boxes, place the engine on the top quarter, block the driving wheels both ways, but do not set the brake. Then open the throttle slightly and move the reverse lever from one end of the quadrant to the other, thereby admitting steam first to one end of the cylinder and then to the other. This action will result in an alternate thrust and pull on the main crankpin and the axle, that will show where the lost motion exists.

If the crown brass is loose, broken, worn, or out of round, the axle will move without moving the driving box; if the faces of the driving box are not parallel the top or bottom of the box will move back and forth between the shoe and the wedge; if the wedge is slack, the whole box will move to and fro. The pedestal binder, if loose, will work on the frame. The brake should not be set when testing, because the brake tends to hold the axle hard against the crown brass, and the driving box against the shoe.

A pound caused by a loose wedge may be remedied by setting up the wedge, but those due to worn, loose, or broken bearings, defective boxes or pedestal caps should be reported and repairs made promptly. If there is too much slack between the crosshead and the guide bars, a very disagreeable pound will result when working the engine hard at slow speed, or at short cut-off; also, there will be a tendency to bend the piston rod and destroy the piston-rod packing. This pound may be stopped by either closing in the guide bars or lining out the crosshead shoes or retinning them as the practice may be.

68. A loose wristpin will cause a pound in the crosshead and if detected should be reported for renewal.

A loose piston rod in the crosshead or the piston causes a severe pound and if not detected and repaired may result in a broken front-cylinder head or cylinder, or both. Pounds in the cylinder such as a loose piston are hard to locate as they appear to be in places other than the cylinder. They may be detected by placing the engine on the quarter, then setting the brake and reversing the engine from forward to back and back to forward with a light throttle. By placing the ear to the

cylinder a pound or thud will be heard when the direction of the piston is reversed and the piston head comes up against the nut or nuts. A loose piston rod in the crosshead may be detected by watching the rod fit in the crosshead when the engine is reversed. A loose piston head, or a piston rod loose in the crosshead, should be reported for repairs as soon as possible after detection.

**69.** The setting up of the wedges due to wear on the shoes causes the axle to move closer to the cylinder, thus moving the piston closer to the front cylinder head; also worn bearings often cut down the cylinder clearance at one end of cylinder. These pounds may be detected by noting on which center the pound occurs or by noting on which end of the guides the crosshead travels up to the bump marks. If the pound occurs on the back dead center or if the crosshead travels to the bump marks on the back end of the guides, the main rod should be lengthened by placing a shim between the front of the main rod brass and removing a like amount from the back so that the bolt holes in the strap will line up with those in the rod. If the pound occurs on the forward center or if the crosshead travels up to the bump marks on the front end of the guides, a shim should be removed from the front of the brass and inserted at the back of it. If a pound develops in the cylinder and the crosshead does not travel up to the bump marks, foreign matter must have got into the cylinder, and the cylinder heads should be taken off and the cause ascertained and remedied.

A stuck driving box usually referred to as a stuck wedge, will cause a pound and heating if stuck up owing to the journal lifting and striking the box when the counterbalance is passing the top quarter. If at a forward driving box, the wheel may derail due to it lifting clear of the rail.

A pound in the right main driving box is more noticeable when backing up because when going ahead, the left crankpin is the trailing pin, and the thrust on it tends to keep the slack from being taken up on the right side. When backing up, the left crankpin leads the right one, the slack is not taken up on the right side, and a pound occurs.

A pound in the left main driving box is more pronounced when going ahead; when backing up the right crankpin is the trailing one, and takes up the slack in the left driving box.

### BLOW-OFF COCKS

**70. Method of Using.**—Blow-off cocks are usually operated by a rod that extends up through the running board. A blow-off cock is generally located on each side of the firebox, at or near the lowest point of the mud ring, but in some cases one is placed in the center of the mud ring at the front of the firebox.

It is a mistake when using the blow-off cocks to fill the boiler up before blowing it out. The reason for using the blow-off cocks is to get rid of the foul water in the boiler, and nothing is to be gained by filling the boiler up and thereby diluting the water with fresh water from the tank. Such a practice is also harmful due to the stresses that are set up in the boiler. However, there should be three gauges of water before the blow-off cocks are opened as this will give more time to get a valve seated should it fail to close.

When operating the blow-off cocks, they should both be opened, if possible, at the same time. They should be held open for about three seconds, and then closed for about six seconds, and this should be continued until the desired amount of water has been blown out.

The reason for opening and closing the cocks in the above manner is to give the sludge in the water legs a chance to collect around the cocks before they are opened again. With the cocks held open continuously, a column of water starts flowing towards them from the upper parts of the boiler and prevents the foul water that is standing around the blow-off cocks from escaping.

When using the blow-off cocks, the quantity of water blown out should not be so great as to require a large amount to be injected again while the engine is standing. Supplying too much water at one time when the water is low causes great differences in temperature between the lower and the upper parts of the boiler and the liability of starting flues and stay-

bolts leaking is greatly increased. Whenever it is possible, water should be supplied when the engine is moving. When the engine is standing the water level should be raised only a little at a time.

### BOILER FEEDING

**71.** The feeding of the boiler has a more important bearing on boiler maintenance than is generally thought to be the case. Improper operation of the injector or feedwater pump results in more destructive stresses in the boiler than any other cause, and is responsible for more boiler leaks than all other causes combined. At ordinary working pressures, the difference between the temperature of the water in the boiler and the temperature of the entering feedwater is about 200° F. When the engine is working the circulation is rapid and the temperatures soon equalize, but if the engine is standing, the temperatures equalize more slowly; the cooler water settles around the firebox sheets and damage results from the contraction that follows. It therefore follows, when the engine is working, that the least damage will be done to the boiler through expansion and contraction, if the water is supplied at about the same rate as it is being used.

When drifting, the water level should not be raised too high unless a good fire is maintained, and when standing, too much water should not be supplied at one time.

**72.** Modern locomotives generally steam freely, and it is not often necessary to trade water for steam as was often the case with lighter power. However, the hauling of the specified tonnage is of the first importance, and if the engine does not steam freely the water level will have to be lowered some in order to maintain full pressure on grades. In such cases, advantage must be taken of stops, drifting, switching, or when the engine is not working to full capacity to increase the height of the water to its proper level.

When hauling heavy trains or making fast time and where the station stops are of any length, it is well to have the water a little down when stopping. The water can then be raised to the proper level while building up the fire and at the same

time the pops will be prevented from blowing off. When the start is made, the water will be at the required level, the fire will be in good condition, and the steam pressure will be high.

If the stop is made with a higher water level, the fire cannot be put in proper shape without causing popping, unless the water level is raised too high.

Special care should be taken in feeding the boiler after the engine arrives at the terminal. The engine frequently stands on the roundhouse tracks for considerable periods after the completion of a trip, and the fire is generally in poor condition. The fire should be built up as much as possible before putting on the injector, and the water level should not be raised too much at one time.

## DERAILMENTS

**73. Car Replacers.**—A top view as well as two side views of a pair of Alexander car replacers is shown in Fig. 20. The three views (*a*) show the outside replacer and the three views (*b*) show the inside replacer. As the name implies, the outside replacer is used to rerail the wheel that is off on the outside of the rail, and the inside replacer to rerail the wheel off on the inside of the rail. The outside replacer can be identified by its greater height as shown in Fig. 20 (*a*); in all other respects the replacers are identical. The outside replacer has to be made higher because it must be designed to carry the flange of the wheel higher than the rail in order that the flange may be carried across the rail when rerailing. The outside replacer is, therefore, the height of the flange or about $1\frac{1}{4}$ inches higher than the inside replacer. To rerail a wheel off on the inside of the rail it is only necessary to raise the tread a little higher than the rail, hence the inside replacer is made lower. Each replacer is curved on the side that comes next to the rail so that the outer ends can be shifted to suit the distance the wheels are away from the rails and at the same time keep their centers close to them.

When rerailing, the tread of the inside wheel is carried on the flange *a*, Fig. 21, of the inside replacer. The wheel flange follows the groove *b* and the flange *c* of the replacer serves to

guide the wheel flange towards the side of the flange *a* provided the wheel flange is not already up against it.

The tread of the outside wheel may ride on either the flange *d* or *e* of the outside replacer depending on the distance of the

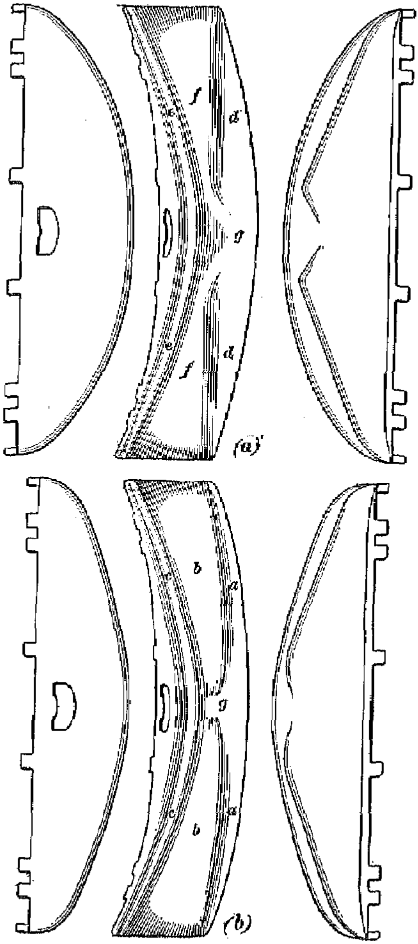



Fig. 20

wheel from the rail. In the former case the wheel flange runs between the replacer and the rail, in the latter the flange will run in the groove *f* in which event the flange *a* of the inside

replacer prevents any movement of the wheels towards the rails until desired.

Near the apex of the replacers the flanges *a* and *d* of each one as well as the grooves *b* and *f* run out and are replaced

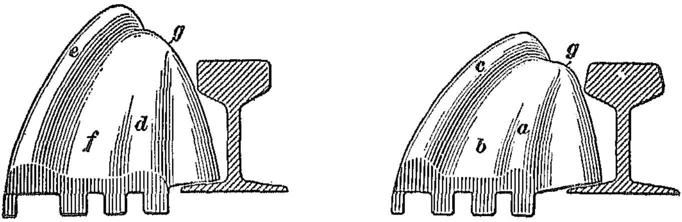



FIG. 21

by the surfaces *g* that slope towards the rail. The wheel on the outside replacer is higher than the other wheel, by the height of its flange, therefore the treads of the wheels when they reach the tops of the replacers, will slip off the sloping surfaces *g* on to the rails. The outside replacer is of such a height that the first part of the slipping movement of the tread carries the flange all of the way across the rail, then the tread drops down on to the rail.

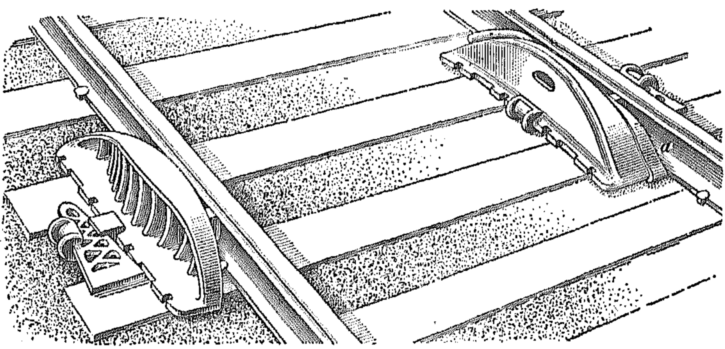



FIG. 22

Each half of a replacer is constructed the same so that the wheels can be pulled on to it from either direction.

74. With the type of replacers shown in Fig. 22 the flange *a* on the inside replacer alone serves to prevent a movement

of the wheels towards the rail until desired. In other respects the operation of both types of replacers is similar. The outside replacer elevates and guides the flange towards the rail in the same manner as the outside replacer in Fig. 20 when the tread is running up on the flange *d*. The flanges and grooves on the inside replacer, Fig. 22, serve the same purpose as similar grooves and flanges on the inside replacer shown in Fig. 20.

**75. Rerailing.**—It is impossible to do more than give general directions for the replacing of engines on the track because the condition in any two cases is seldom the same. In the event of two or three pairs of wheels dropping off the rails at slow speed it may be possible to rerail the engine under her own power, depending upon the condition of the track; how far the wheels have cut down into the ties and ballast; also whether the ties are spaced close together or quite a distance apart. The season of the year also makes a difference as it is easier to rerail an engine when the ballast is frozen than when it is not.

In rerailing, an engine will generally go on the rails the easiest by taking it back over the same route it went off.

In case an engine runs off the track, a few minutes' inspection should show whether or not an effort should be made to rerail without assistance. If the wheels are close to the rails and have not settled down in the roadbed and all the driving wheels are not off the track, it may be possible to rerail the engine without sending for assistance, by means of a set of car replacers, hardwood blocks, shims or wedges, fishplates or any other material that is available.

When there is only one pair of wheels off the track, a set of car replacers should be placed close up against the wheels with the inside replacer so placed that there is just enough space between the replacer and the ball of the rail for the flange of the wheel to enter as it rerails. The outside replacer should be placed as close as possible to the rail; the caulks on the bottom of replacers pressing in the ties will generally hold the replacers in place. If the replacer is so placed on the ties that the caulks cannot hold, or when used on a truck that is badly

askew, or when snow, ice, or sandy or muddy conditions prevail it is usually better to spike the replacers in place.

When more than one pair of wheels are off the track, hardwood shims, fishplates or any other suitable material that is available should be placed between the ties so as to provide a fairly level surface for the wheels to run on when leading up to the replacers, and to prevent them from sinking into the ballast.

**76.** In some cases another engine may be necessary to assist in pulling the derailed one on the track. The engineer of the one that is pulling should always be prepared to stop quickly in case things do not go just as expected. Good judgment must be exercised in placing the wedges or replacers in position, for a little thought in regard to this may save hours of hard work.

It frequently happens that engines get off the track in such a way that nothing can be done towards getting them on again without the use of heavy tools. In such cases, no time should be lost in sending for the wrecking car and crew. If the engine is off the track in such a manner that the water connections between the engine and tender are broken it may be necessary to draw the fire. This will depend on the height of the water and the condition of the fire.

If the engine has to be jacked up, considerable work can be saved by putting nuts or pieces of iron between the bottom of the driving box and the pedestal binders, so that the wheels will lift with the frame. As the engine is lifted blocking should be put in place underneath it to "hold good" all that the engine is raised. Before jacking or lifting the engine, the engine truck should be chained to the frame so that it will be raised with the engine.

If the truck wheels stand at an angle they should be pulled or jacked into line. When the engine has been raised high enough, cross ties may be laid and rails may be put under the wheels. Then the best way to get the engine on the main track will be to break the joints and swing the end of the rails around far enough to connect with the rails on which the

engine rests; the engine may then be moved out, the main track swung back, and the rails again connected.

With large, heavy engines, the rerailing of any of the wheels will be found to be very difficult, and in most of the cases it is best to immediately send for the wrecking crew, as they will rerail an engine with less delay to traffic. Exception may be made to this practice when only the engine or tender truck is off the track and can be replaced without much delay.

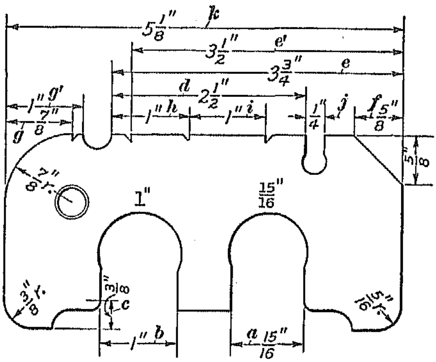



FIG. 23

## WHEEL DEFECT, WORN COUPLER LIMIT, WORN JOURNAL COLLAR AND JOURNAL FILLET GAGE

**77. Explanation of Use.**—In Fig. 23 is shown a view of the standard wheel defect, worn coupler limit, worn journal collar and journal fillet gauge with reference letters added to the dimensions in order to prevent any misunderstanding of their purpose in the explanation that follows: The rules referred to in the following will be found in the abstract from the Rules and Instructions for Inspection and Testing of Steam Locomotives and Tenders in the back of this lesson paper.

*Dimension a*, $\frac{15}{16}$ inch, is used to gauge the thickness of the flanges of all wheels. See Rules 145 (*h*), 146 (*f*), and 150 (*h*).

*Dimension b*, 1 inch, is used to gauge the thickness of the flanges of cast-iron or cast-steel wheels with a specified size of journal. See Rule 145 (*h*).

*Dimension c*, $\frac{3}{8}$ inch, insures that the gauging prescribed by Rules 145 (*h*), 146 (*f*), and 150 (*h*) is done at the prescribed distance above the tread.

*Dimension d*, $2\frac{1}{2}$ inches, is used to gauge flat spots, cracks, and shelled-out spots. See Rules 145 (*b*), 145 (*c*), 146 (*d*), and 150 (*h*).

*Dimension* (*e*), $3\frac{3}{4}$ inches, is used to gauge broken rims and the distance seams are from the flange. See Rules 145 (*d*) and 145 (*g*).

*Dimension e′*, $3\frac{1}{2}$ inches. Rule 145 (*d*) does not mention whether the fracture inclines in or out. The Rules of Interchange permit the $3\frac{1}{2}$-inch dimension if the fracture inclines outwards and the $3\frac{3}{4}$-inch dimension if the fracture inclines inwards.

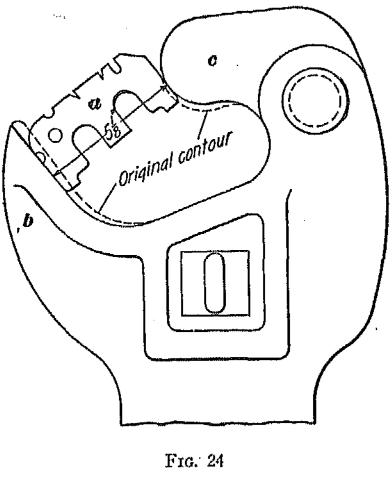



FIG. 24

*Dimension f*, $\frac{5}{8}$ inch, insures that the gauging prescribed by Rule 145 (*d*) is done at the prescribed height above the flange.

*Dimension g*, $\frac{7}{8}$ inch, is used to gauge flanges with flat vertical surfaces on certain classes of wheels. See Rule 145 (*h*).

*Dimension g′*, 1 inch, is also used to gauge flanges with flat vertical surfaces on certain classes of wheels. See Rules 146 (*f*) and 150 (*h*). The vertical flange rule is to prevent wheels from running which may split a switch.

It should be noted, however, that the accuracy of the gauging for vertical flanges depends on a straight horizontal portion of the tread on which to place the gauge. See Fig. 10 in the Abstract from Federal Inspection Rules in back of this lesson paper. Such a tread is found only on a new tire, because this portion of the tread is no longer straight after the tire has been in service for a month or two. Therefore, judgment must be used in gauging, otherwise tires may be condemned for vertical flanges that might be used with safety for several months longer.

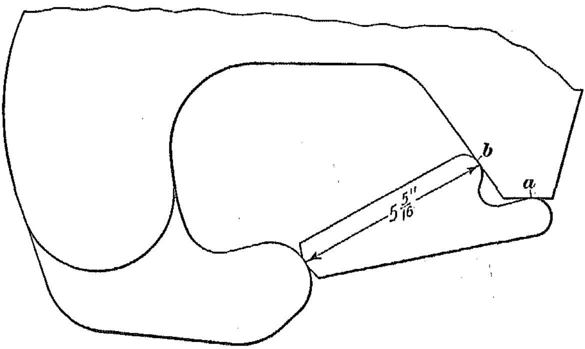



Fig. 25

*Dimension* $h+i$, 1 inch+1 inch, is used to gauge two or more adjoining flat spots. See Rules 145 (*b*) and 146 (*c*).

*Dimension* $j$, $\frac{1}{4}$ inch, is used to gauge the collars on journals of tender truck axles and car axles. See Rule 135 (*b*).

*Dimension* $k$, $5\frac{1}{8}$ inches, is used to measure the extent of the wear between the point of the knuckle and the guard arm, of MCB contour 1904 couplers. If the distance between $b$ and $c$, Fig. 24, exceeds $5\frac{1}{8}$ inches, the defective parts must be renewed to bring the coupler within gauge. The condemning limit of type D and E couplers is $5\frac{5}{16}$ inches, and the gauge used is shown applied in Fig. 25, with the points $a$ and $b$ contacting the guard arm.

The $\frac{5}{16}$*-inch radius* is used to gauge the fillet on the back or dust guard end of the journal of a tender or a car. See

Rule 135 (*b*). If this fillet is found to have a radius of less than $\frac{5}{16}$ inch and the capacity of the car is between 50,000 and 60,000 pounds, the Rules of Interchange specify that the axle is to be condemned.

The $\frac{3}{8}$-*inch radius* is used to gauge the fillet on axles of cars in excess of 60,000 pounds capacity. If this fillet is found to have a radius of less than $\frac{3}{8}$ inch, the Rules of Interchange specify that the axle is to be condemned. Axles are liable to crack at the fillets if they are worn out, as this makes a sharp corner.

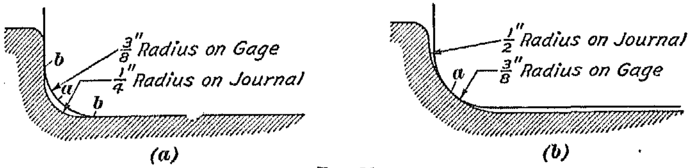



Fig. 26

The use of the $\frac{3}{8}$-inch radius is illustrated in Fig. 26, where it is shown applied to a journal of a car with a capacity in excess of 60,000 pounds. In view (*a*) is shown a journal with the fillet worn until the radius is less than $\frac{3}{8}$ inch, in which event the center of the radius *a* midway between the two tangents *b* does not make contact with the fillet, hence the axle is condemned. In view (*b*) the point *a* makes contact with the fillet, so that the journal is passed.

**78. Gauging Flange Height, Tread Wear, and Tire Thickness.**—No specified type of gauge is prescribed to measure the height of the flange, the tread wear, and the thickness of the tire as prescribed by Rules 146 (*f*), 150 (*h*), and 151 (*a*), but one of the type shown in Fig. 27 may be used for this purpose. It consists of a steel square with three adjustable fingers. The head of the square is applied to the back of the tire and two of the fingers are brought into contact with the lowest and the highest point of the tread. The outside finger is adjusted until it is in line with the inside of the tire; the three thumbscrews are then tightened. The gauge can now be removed from the tire without affecting the readings.

The height of the flange can be obtained by a direct reading on the first finger. The tread wear is found by substracting the reading of the second finger from that of the first finger. The tire thickness is found by subtracting the reading of the first finger from that of the third finger.

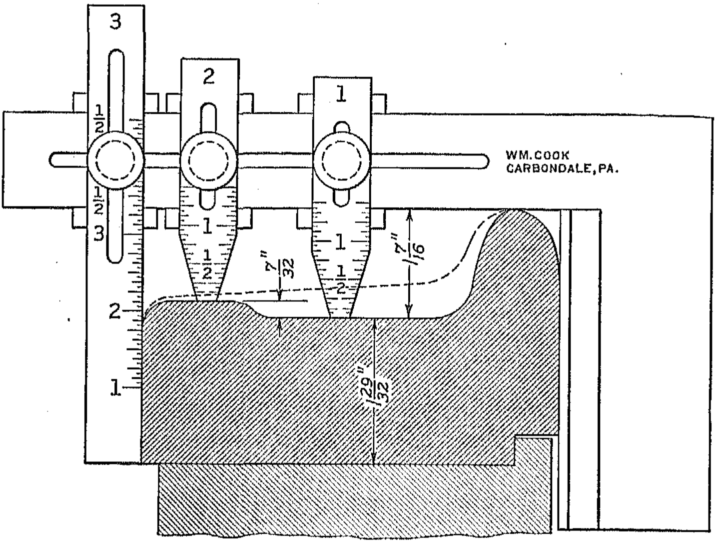



FIG. 27

The worn tire in Fig. 27 shows a flange height of $1\frac{7}{16}$ inches, a tread wear of $1\frac{7}{16}-1\frac{7}{32}$, or $\frac{7}{32}$ inch, and a tire thickness of $3\frac{11}{32}-1\frac{7}{16}$, or $1\frac{29}{32}$ inches.

## ABSTRACT FROM RULES AND INSTRUCTIONS FOR INSPECTION AND TESTING OF STEAM LOCOMOTIVES AND TENDERS.

### IN ACCORDANCE WITH THE ACT OF MARCH 4, 1915, AMENDING THE ACT OF FEBRUARY 17, 1911.

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Approved by orders of the Interstate Commerce Commission, dated October 11, 1915, June 30, 1916, November 13, 1916, December 26, 1916, December 17, 1917, April 7, 1919, May 7, 1928, and February 21, 1929.

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101. The railroad company will be held responsible for the general design, construction, and maintenance of locomotives and tenders under its control.

102. The mechanical officer in charge, at each point where repairs are made, will be held responsible for the inspection and repair of all parts of locomotives and tenders under his jurisdiction. He must know that inspections are made as required and that the defects are properly repaired before the locomotive is returned to service.

103. The term "inspector" as used in these rules and instructions means, unless otherwise specified, the railroad company's inspector.

104. Each locomotive and tender shall be inspected after each trip, or day's work, and the defects found reported on an approved form to the proper representative of the company. This form shall show the name of the railroad, the initials and number of the locomotive, the place, date, and time of the inspection, the defects found, and the signature of the employee making the inspection. The report shall be approved by the foreman, with proper written explanation made thereon for defects reported which were not repaired before the locomotive is returned to service. The report shall then be filed in the office of the railroad company at the place where the inspection is made. (See Form 2.)

#### ASH PANS.

105. (*a*) Ash pans shall be securely supported and maintained in safe and suitable condition for service.

(*b*) Locomotives built after January 1, 1916, shall have ash pans supported from mud rings or frames. Locomotives built prior to January 1, 1916, which do not have the ash pans supported from mud rings or frames shall be changed when the locomotive receives new fire box.

(*c*) The operating mechanism of all ash pans shall be so arranged that it may be safely operated and maintained in safe and suitable condition for service.

(*d*) No part of ash pan shall be less than 2½ inches above the rail.

### BRAKE AND SIGNAL EQUIPMENT

106. It must be known before each trip that the brakes on locomotive and tender are in safe and suitable condition for service; that the air compressor or compressors are in condition to provide an ample supply of air for the service in which the locomotive is put; that the devices for regulating all pressures are properly performing their functions; that the brake valves work properly in all positions; and that the water has been drained from the air-brake system.

107. (*a*) *Compressors.*—The compressor or compressors shall be tested for capacity by orifice test as often as conditions may require, but not less frequently than once each three months.

(*b*) The diameter of orifice, speed of compressor, and the air pressure to be maintained for compressors in common use are given in the following table:

| Make. | Size compressor. | Single strokes per minute. | Diameter of orifice. | Air pressure maintained. |
|---|---|---|---|---|
| | | | *Inches.* | *Pounds.* |
| Westinghouse | $9\frac{1}{2}$ | 120 | $\frac{11}{64}$ | 60 |
| Do | 11 | 100 | $\frac{3}{16}$ | 60 |
| Do | $8\frac{1}{2}$ c. c. | 100 | $\frac{9}{32}$ | 60 |
| New York | 2a | 120 | $\frac{5}{32}$ | 60 |
| Do | 6a | 100 | $\frac{13}{64}$ | 60 |
| Do | 5b | 100 | $\frac{15}{64}$ | 60 |

For diagram of orifice see figure No. 14.
This table shall be used for altitudes to and including 1,000 feet. For altitudes over 1,000 feet the speed of compressor may be increased 5 single strokes per minute for each 1,000 feet increase in altitude.

108. (*a*) *Testing main reservoirs.*—Every main reservoir before being put into service, and at least once each 12 months thereafter, shall be subjected to hydrostatic pressure not less than 25 per cent above the maximum allowed air pressure.

(*b*) The entire surface of the reservoir shall be hammer tested each time the locomotive is shopped for general repairs, but not less frequently than once each 18 months.

109. (*a*) *Air gauges.*—Air gauges shall be so located that they may be conveniently read by the engineer from his usual position in the cab. Air gauges shall be tested at least once each three months, and also when any irregularity is reported.

(*b*) Air gauges shall be compared with an accurate test gauge or dead weight tester, and gauges found incorrect shall be repaired before they are returned to service.

110. *Time of cleaning.*—Distributing or control valves, reducing valves, triple valves, straight-air double-check valves, and dirt collectors shall be cleaned as often as conditions require to maintain them in a safe and suitable condition for service, but not less frequently than once every six months.

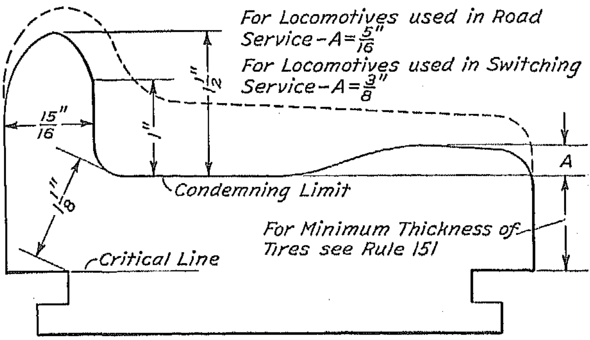


FIG. 1

111. (*a*) *Stenciling dates of tests and cleaning.*—The date of testing or cleaning, and the initials of the shop or station at which the work is done, shall be legibly stenciled in a conspicuous place on the parts, or placed on a card displayed under glass in the cab of the locomotive, or stamped on metal tags. When metal tags are used, the height of letters and figures shall be not less than three-eighths inch, and the tags located as follows:

(*b*) One securely attached to brake pipe near automatic brake valve, which will show the date on which the distributing valve, control valve or triple valves, reducing valves, straight-air double-check valves, dirt collectors, and brake cylinders were cleaned and cylinders lubricated.

(*c*) One securely attached to air compressor steam pipe, which will show the date on which the compressor was tested by orifice test.

(*d*) One securely attached to the return pipe near main reservoir, which will show the date on which the hydrostatic test was applied to main reservoirs.

112. (*a*) *Piston travel.*—The minimum piston travel shall be sufficient to provide proper brake shoe clearance when the brakes are released.

(*b*) The maximum piston travel when locomotive is standing shall be as follows:

| | *Inches.* |
|---|---|
| Cam type of driving wheel brake | $3\frac{1}{2}$ |
| Other forms of driving wheel brake | 6 |
| Engine truck brake | 8 |
| Tender brake | 9 |

113. (*a*) *Foundation brake gear.*—Foundation brake gear shall be maintained in a safe and suitable condition for service. Levers, rods, brake beams, hangers, and pins shall be of ample strength, and shall not be fouled in any way which will affect the proper operation of the brake. All pins shall be properly secured in place with cotters, split keys, or nuts. Brake shoes must be properly applied and kept approximately in line with the tread of the wheel.

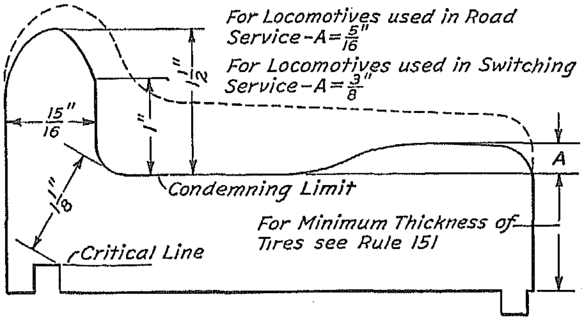


FIG. 2

(*b*) No part of the foundation brake gear of the locomotive or tender shall be less than 2½ inches above the rails.

114. (*a*) *Leakage.*—Main reservoir leakage; leakage from main reservoir and related piping shall not exceed an average of 3 pounds per minute in a test of three minutes' duration, made after the pressure has been reduced 40 per cent below maximum pressure.

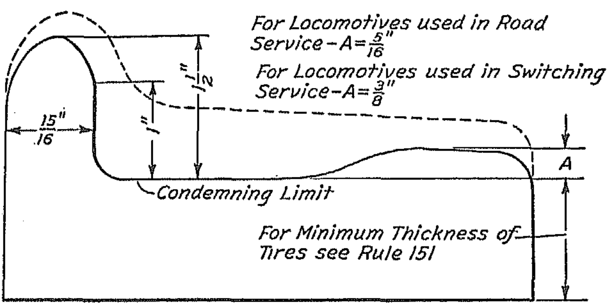


FIG. 3

(*b*) Brake pipe leakage shall not exceed 5 pounds per minute.

(*c*) *Brake cylinder leakage.*—With a full service application from maximum brake pipe pressure, and with communication to the brake cylinders closed, the brakes on the locomotive and tender shall remain applied not less than five minutes.

115. *Train signal system.*—The train signal system, when used, shall be tested and known to be in safe and suitable condition for service before each trip.

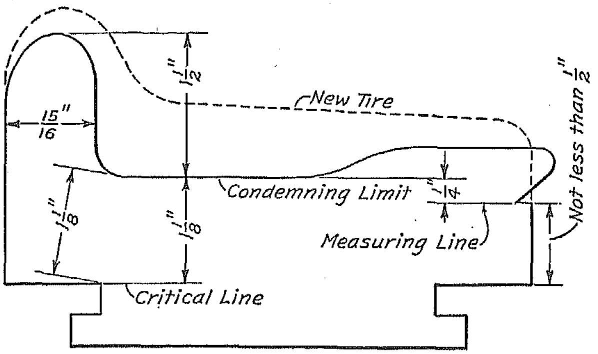


FIG. 4

CABS, WARNING SIGNALS, AND SANDERS.

116. (*a*) *Cabs.*—Cabs shall be securely attached or braced and maintained in a safe and suitable condition for service. Cab windows shall be so located and maintained that the enginemen may have a clear view of track and signals from their usual and proper positions in the cab.

(*b*) Road locomotives used in regions where snowstorms are generally encountered shall be provided with what is known as a "clear vision" window, which is a window hinged at the top and placed in the glass in each front cab door or window. These windows shall be not less than 5 inches high, located as nearly as possible in line of the enginemen's vision, and so constructed that they may be easily opened or closed.

(*c*) Steam pipes shall not be fastened to the cab. On new construction or when renewals are made of iron or steel pipe subject to boiler pressure in cabs, it shall be what is commercially known as double strength pipe, with extra heavy valves and fittings.

117. *Cab aprons.*—Cab aprons shall be of proper length and width to insure safety. Aprons must be securely hinged, maintained in a safe and suitable condition for service, and roughened, or other provision made, to afford secure footing.

118. (*a*) Each locomotive shall have a mechanically operated fire door (or fire doors if more than one is used) so constructed and maintained that it may be operated by pressure of the foot on a pedal, or other suitable appliance, located on the floor of the cab or tender at a suitable distance from the fire door, so that it may be conveniently operated by the person firing the locomotive: *Provided,* That locomotives burning oil fuel

may have in lieu of the mechanically operated fire door a hand-operated fire door of suitable construction and so arranged that it may be securely bolted in closed position while the locomotive is being used.

(*b*) Fire doors shall be maintained in a safe and suitable condition for service.

119. *Cylinder cocks.*—Necessary cylinder cocks, operative from cab of locomotive, shall be provided and maintained in a safe and suitable condition for service.

120. *Sanders.*—Locomotives shall be equipped with proper sanding apparatus, which shall be maintained in safe and suitable condition for service, and tested before each trip. Sand pipes must be securely fastened in line with the rails.

121. *Whistle.*—Each locomotive must be provided with a suitable steam whistle, so arranged that it may be conveniently operated by the engineer.

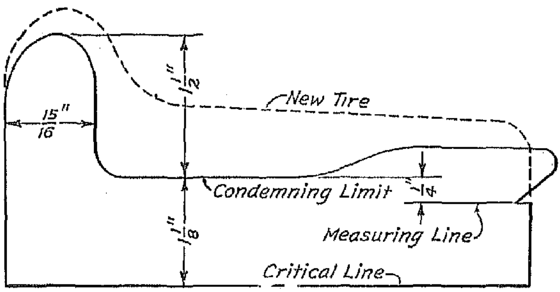


FIG. 5

DRAW GEAR AND DRAFT GEAR.

122. (*a*) *Draw gear between locomotive and tender.*—The draw gear between the locomotive and tender, together with the pins and fastenings, shall be maintained in safe and suitable condition for service. The pins and drawbar shall be removed and carefully examined for defects not less frequently than once each three months. Suitable means for securing the drawbar pins in place shall be provided. Inverted drawbar pins shall be held in place by plate or stirrup.

(*b*) Two or more safety bars or safety chains of ample strength shall be provided between locomotive and tender, maintained in safe and suitable condition for service, and inspected at the same time draw gear is inspected.

(*c*) Safety chains or safety bars shall be of the minimum length consistent with the curvature of the railroad on which the locomotive is operated.

(*d*) Lost motion between locomotives and tenders not equipped with spring buffers shall be kept to a minimum, and shall not exceed one-half inch.

(*e*) When spring buffers are used between locomotive and tender the spring shall be applied with not less than three-fourths inch compression, and shall at all times be under sufficient compression to keep the chafing faces in contact.

123. *Chafing irons.*—Chafing irons of such radius as will permit proper curving shall be securely attached to locomotive and tender, and shall be maintained in condition to permit free movement laterally and vertically.

124. *Draft gear.*—Draft gear and attachments on locomotives and tenders shall be securely fastened, and maintained in safe and suitable condition for service.

DRIVING GEAR.

125. *Crossheads.*—Crossheads shall be maintained in a safe and suitable condition for service, with not more than one-fourth inch vertical or five-sixteenths inch lateral play between crossheads and guides.

126. *Guides.*—Guides must be securely fastened and maintained in a safe and suitable condition for service.

127. (*a*) *Pistons and piston rods.*—Pistons and piston rods shall be maintained in safe and suitable condition for service. Piston rods shall be carefully examined for cracks each time they are removed, and shall be renewed if found defective.

(*b*) All piston rods applied after January 1, 1916, shall have the date of application, original diameter, and kind of material legibly stamped on or near the end of rod.

128. (*a*) *Rods, main and side.*—Cracked or defective main or side rods shall not be continued in service.

(*b*) Autogenous welding of broken or cracked main and side rods not permitted.

(*c*) Bearings and bushings shall so fit the rods as to be in a safe and suitable condition for service, and means be provided to prevent bushings turning in rod. Straps shall fit and be securely bolted to rods.

(*d*) The total amount of side motion of rods on crank pins shall not exceed one-fourth inch.

(*e*) Oil and grease cups shall be securely attached to rods, and grease cup plugs shall be equipped with suitable fastenings.

(*f*) *Locomotives used in road service.*—The bore of main rod bearings shall not exceed pin diameters more than three thirty-seconds inch at front or back end. The total lost motion at both ends shall not exceed five thirty-seconds inch.

(*g*) The bore of side rod bearings shall not exceed pin diameters more than five thirty-seconds inch on main pin nor more than three-sixteenths inch on other pins.

(*h*) *Locomotives used in yard service.*—The bore of main rod bearings shall not exceed pin diameters more than one-eighth inch at front end or five thirty-seconds inch at back end.

(*i*) The bore of side rod bearings shall not exceed pin diameter more than three-sixteenths inch.

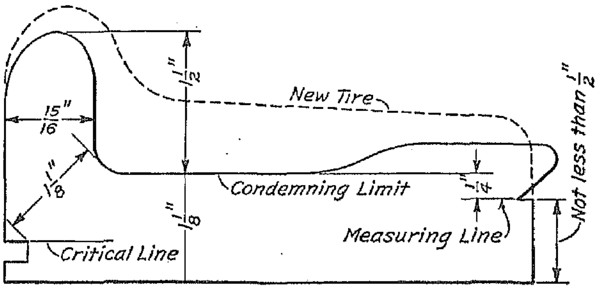


FIG. 6

LIGHTS.

129. (*a*) *Locomotives used in road service.*—Each locomotive used in road service between sunset and sunrise shall have a headlight which shall afford sufficient illumination to enable a person in the cab of such locomotive who possesses the usual visual capacity required of locomotive enginemen, to see in a clear atmosphere, a dark object as large as a man of average size standing erect at a distance of at least 800 feet ahead and in front of such headlight; and such headlight must be maintained in good condition.

(*b*) Each locomotive used in road service, which is regularly required to run backward for any portion of its trip, except to pick up a detached portion of its train, or in making terminal movements, shall have on its rear a headlight which shall meet the foregoing requirements.

(*c*) Such headlights shall be provided with a device whereby the light from same may be diminished in yards and at stations or when meeting trains.

(*d*) When two or more locomotives are used in the same train, the leading locomotive only will be required to display a headlight.

130. *Classification lamps.*—Each locomotive used in road service shall be provided with such classification lamps as may be required by the rules of the railroad company operating the locomotive. When such classification lamps are provided they shall be kept clean and maintained in safe and suitable condition for service.

131. *Locomotives used in yard service.*—Each locomotive used in yard service between sunset and sunrise shall have two lights, one located on the front of the locomotive and one on the rear, each of which shall enable a person in the cab of the locomotive under the conditions, including visual capacity, set forth in rule 129, to see a dark object such as there described for a distance of at least 300 feet ahead and in front of such headlight; and such headlights must be maintained in good condition.

132. *Cab lights.*—Each locomotive used between sunset and sunrise shall have cab lamps which will provide sufficient illumination for the steam, air, and water gauges to enable the enginemen to make necessary and accurate readings from their usual and proper positions in the cab. These lights shall be so located and constructed that the light will shine only on those parts requiring illumination. Locomotives used in road service shall have an additional lamp conveniently located to enable the persons operating the locomotive to easily and accurately read train orders and time tables, and so constructed that it may be readily darkened or extinguished.

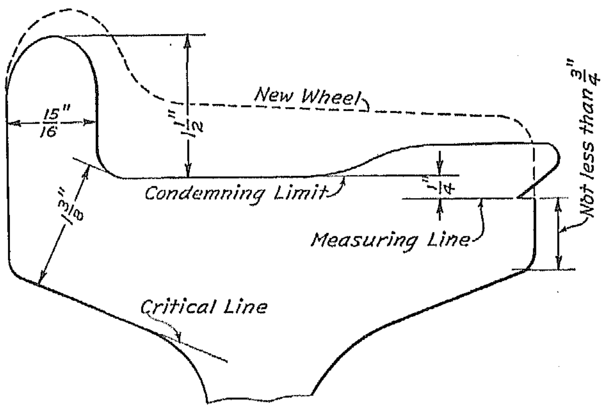


Fig. 7

RUNNING GEAR.

133. (*a*) *Driving, trailing, and engine truck axles.*—Driving, trailing, and engine truck axles with any of the following defects shall not be continued in service:

(*b*) Bent axle; cut journals that can not be made to run cool without turning; seamy journals in steel axles; transverse seams in iron axles, or any seams in iron axles causing journals to run hot, or unsafe on account of usage, accident, or derailment; driving, trailing, or engine truck axles more than one-half inch under original diameter, except for locomotives having all driving axles of the same diameter, when other

than main driving axles, may be worn three-fourths inch below the original diameter.

(*c*) The date applied, the original diameter of the journal, and the kind of material shall be legibly stamped on one end of each driving axle, trailing truck axle, and engine truck axle applied after January 1, 1916.

134. *Tender truck axles.*—The minimum diameters of axles for various axle loads shall be as follows:

| Axle load. | Minimum diameter of journal. | Minimum diameter of wheel seat. | Minimum diameter of center. |
|---|---|---|---|
| | *Inches.* | *Inches.* | *Inches.* |
| 50,000 pounds | $5\frac{1}{2}$ | $7\frac{3}{8}$ | $6\frac{7}{16}$ |
| 38,000 pounds | 5 | $6\frac{3}{4}$ | $5\frac{7}{8}$ |
| 31,000 pounds | $4\frac{1}{2}$ | $6\frac{1}{4}$ | $5\frac{5}{16}$ |
| 22,000 pounds | $3\frac{3}{4}$ | 5 | $4\frac{3}{8}$ |
| 15,000 pounds | $3\frac{1}{4}$ | $4\frac{5}{8}$ | $3\frac{7}{8}$ |

135. (*a*) Tender truck axles with any of the following defects shall not be continued in service:

(*b*) Bent axle; cut journals that can not be made to run cool without turning; seamy journals in steel axles, or transverse seams in journals of iron axles, or unsafe on account of usage, accident, or derailment; collars broken or worn to one-fourth inch or less in thickness; fillet in back shoulder worn out.

136. (*a*) *Crank pins.*—Crank pins shall be securely applied. Shimming or prick punching crank pins will not be allowed. All crank pins applied after January 1, 1916, shall have the date applied and kind of material used legibly stamped on end of pin.

(*b*) Crank pin collars and collar bolts shall be maintained in a safe and suitable condition for service.

137. *Driving boxes.*—Driving boxes shall be maintained in a safe and suitable condition for service. Broken and loose bearings shall be renewed. Not more than one shim may be used between box and bearings.

138. *Driving box shoes and wedges.*—Driving box shoes and wedges shall be maintained in a safe and suitable condition for service.

139. *Frames.*—Frames, deck plates, tailpieces, pedestals, and braces shall be maintained in a safe and suitable condition for service, and shall be cleaned and thoroughly inspected each time the locomotive is in shop for heavy repairs.

140. (*a*) *Lateral motion.*—The total lateral motion or play between the hubs of the wheels and the boxes on any pair of wheels shall not exceed the following limits:

| | Inch. |
|---|---|
| For engine truck wheels (trucks with swing centers) | 1 |
| For engine truck wheels (trucks with rigid centers) | 1½ |
| For trailing truck wheels | 1 |
| For driving wheels (more than one pair) | ¾ |

(*b*) These limits may be increased on locomotives operating on track where the curvature exceeds 20 degrees when it can be shown that conditions require additional lateral motion.

(*c*) The lateral motion shall in all cases be kept within such limits that the driving wheels, rods, or crank pins will not interfere with other parts of the locomotive.

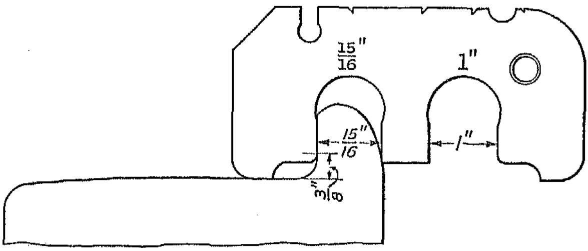


Fig. 9

141. (*a*) *Pilots.*—Pilots shall be securely attached, properly braced, and maintained in a safe and suitable condition for service.

(*b*) The minimum clearance of pilot above the rail shall be 3 inches, and the maximum clearance 6 inches.

142. (*a*) *Spring rigging.*—Springs and equalizers shall be arranged to insure the proper distribution of weight to the various wheels of the locomotive, maintained approximately level and in a safe and suitable condition for service.

(*b*) Springs or spring rigging with any of the following defects shall be renewed or properly repaired:

(*c*) Top leaf broken or two leaves in top half or any three leaves in spring broken. (The long side of spring to be considered the top.)

(*d*) Springs with leaves working in band.

(*e*) Broken coil springs.

(*f*) Broken driving box saddle, equalizers, hanger, bolt, or pin.

143. (*a*) *Trucks, leading and trailing.*—Trucks shall be maintained in safe and suitable condition for service. Center plates shall fit properly, and the male center plate shall extend into the female center plate not less than three-fourths inch. All centering devices shall be properly maintained.

(*b*) A suitable safety chain shall be provided at each front corner of all four wheel engine trucks.

(*c*) All parts of trucks shall have sufficient clearance to prevent them from seriously interfering with any other part of the locomotive.

144. (*a*) *Wheels.*—Wheels shall be securely pressed on axles. Prick punching or shimming the wheel fit will not be permitted. The diameter of wheels on the same axle shall not vary more than three thirty-seconds inch.

(*b*) Wheels used on standard gauge track will be out of gauge if the inside gauge of flanges, measured on base line, is less than 53 inches or more than 53⅜ inches.

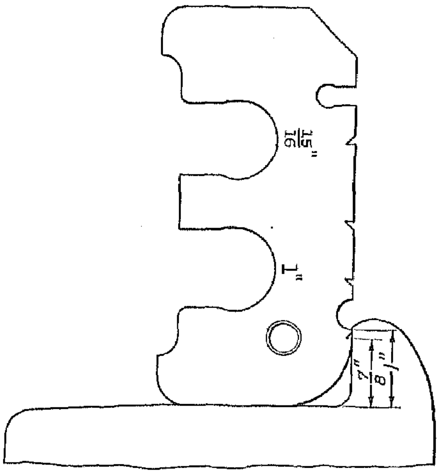


FIG. 10

(*c*) The distance back to back of flanges of wheels mounted on the same axle shall not vary more than one-fourth inch.

145. (*a*) *Cast-iron or cast-steel wheels.*—Cast iron or cast-steel wheels with any of the following defects shall not be continued in service:

(*b*) *Slid flat.*—When the flat spot is 2½ inches or over in length, or if there are two or more adjoining spots each 2 inches or over in length.

(*c*) *Broken or chipped flange.*—If the chip exceeds 1½ inches in length and one-half inch in width.

(*d*) *Broken rim.*—If the tread, measured from the flange at a point five-eighth inch above the tread, is less than 3¾ inches in width.

(*e*) *Shelled out.*—Wheels with defective treads on account of cracks or shelled out spots 2½ inches or over, or so numerous as to endanger the safety of the wheel.

(*f*) *Brake burn.*—Wheels having defective tread on account of cracks or shelling out due to heating.

(*g*) Seams one-half inch long or over, at a distance of one-half inch or less from the throat of the flange, or seams 3 inches or more in length, If such seams are within the limits of 3¾ inches from the flange, measured at a point five-eighths inch from the tread.

(*h*) *Worn flanges.*—Wheels on axles with journals 5 inches by 9 inches or over with flanges having flat vertical surfaces extending seven-eighths inch or more from the tread, or flanges 1 inch thick or less gauged at a point three-eighths inch above tread. Wheels on axles with journals less than 5 inches by 9 inches with flanges having flat vertical surfaces extending 1 inch or more from the tread, or flanges fifteenth-sixteenths inch thick or less, gauged at a point three-eighths inch above the tread.

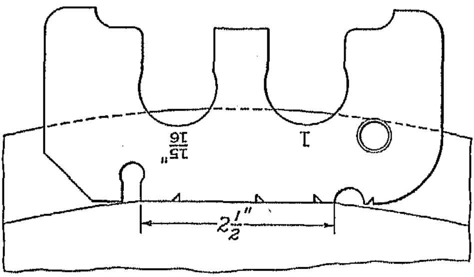


Fig. 11

(*i*) *Tread worn hollow.*—If the tread is worn sufficiently hollow to render the flange or rim liable to breakage.

(*j*) *Burst.*—If the wheel is cracked from the wheel fit outward.

(*k*) Cracked tread, cracked plate, or one or more cracked brackets.

(*l*) Wheels out of gauge.

(*m*) Wheels loose on axle.

Note.—The determination of flat spots, worn flanges, and broken rims shall be made by a gauge as shown in figure 23 (page 68), and its application to defective wheels as shown in figures 9, 10, 11, 12, and 13.

146. (*a*) *Forged steel or steel tired wheels.*—Forged steel or steel tired wheels with any of the following defects shall not be continued in service:

(*b*) Loose wheels; loose, broken, or defective retaining rings or tires; broken or cracked hubs, plates, spokes, or bolts.

(*c*) Slid flat spot 2½ inches or longer; or, if there are two or more adjoining spots, each 2 inches or longer.

(*d*) Defective tread on account of cracks or shelled out spots 2½ inches or longer, or so numerous as to endanger the safety of the wheel.

(*e*) Broken flange.

(*f*) Flange worn to fifteen-sixteenths inch or less in thickness, gauged at a point three-eighths inch above the tread, or having flat vertical surface, 1 inch or more from tread; tread worn five-sixteenths inch; flange more than 1½ inches from tread to top of flange, or thickness of tires or rims less than shown in figures 4, 5, 6, and 7.

(*g*) Wheels out of gauge.

147. *Driving and trailing wheels.*—Driving and trailing wheel centers with divided rims shall be properly fitted with iron or steel filling blocks before the tires are applied, and such filling blocks shall be properly maintained. When shims are inserted between the tire and the wheel center, not more than two thicknesses of shims may be used, one of which must extend entirely around the wheel.

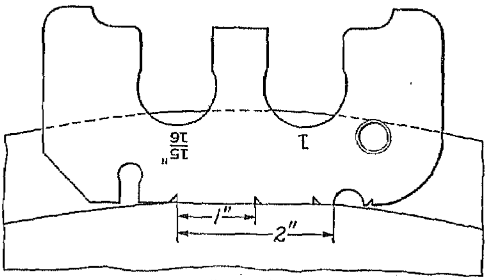


FIG. 12

148. Driving wheel counterbalance shall be maintained in a safe and suitable condition for service.

149. (*a*) Driving and trailing wheels with any of the following defects shall not be continued in service:

(*b*) Driving or trailing wheel centers with three adjacent spokes or 25 per cent of the spokes in wheel broken.

(*c*) Loose wheels; loose, broken, or defective tires or tire fastenings; broken or cracked hubs, or wheels out of gauge.

150. (*a*) *Driving and trailing wheel tires.*—The minimum height of flange for driving or trailing wheel tires, measured from tread, shall be 1 inch for locomotives used in road service, except that on locomotives where construction will not permit the full height of flange on all drivers the minimum height of flange on one pair of driving wheels may be five-eighths inch.

(*b*) The minimum height of flange for driving wheel tires, measured from tread, shall be seven-eighths inch for locomotives used in switching service.

(*c*) The maximum taper for tread of tires from throat of flange to outside of tire, for driving and trailing wheels for locomotives used in road service, shall be one-fourth inch, and for locomotives used in switching service *five-sixteenths inch.*

(*d*) The minimum width of tires for driving and trailing wheels of standard-gauge locomotives shall be 5½ inches for flanged tires, and 6 inches for plain tires.

(*e*) The minimum width of tires for driving and trailing wheels of narrow-gauge locomotives shall be 5 inches for flanged tires, and 5½ inches for plain tires.

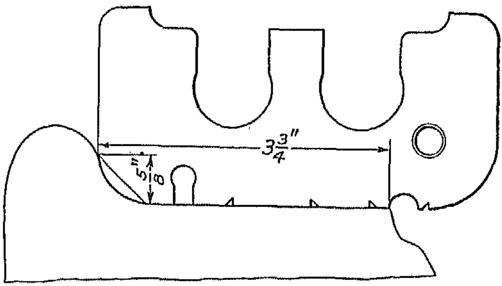


FIG. 13

(*f*) When all tires are turned or new tires applied to driving and trailing wheels, the diameter of the wheels on the same axle, or in the same driving wheel base, shall not vary more than three thirty-seconds inch. When a single tire is applied the diameter must not vary more than three thirty-seconds inch from that of the opposite wheel on the same axle. When a single pair of tires is applied the diameter must be within three thirty-seconds inch of the average diameter of the wheels in the driving wheel base to which they are applied.

(*g*) Driving and trailing wheel tires with any of the following defects shall not be continued in service:

(*h*) Slid flat spot 2½ inches or more in length; flange fifteen-sixteenths inch or less in thickness, gauged at a point three-eighths inch above the tread; or having flat vertical surface 1 inch or more from tread; tread worn hollow five-sixteenths inch on locomotives used in road service, or three-eighths inch on locomotives used in switching service; flange more than 1½ inches from tread to top of flange. (See figs. 1, 2, and 3.)

NOTE.—The determination of flat spots and worn flanges shall be made by a gauge as shown in figure 23 (page 68), and its application to defective tires as shown in figures 9, 10, and 11.

151. *(a) Minimum thickness for driving wheel and trailer tires on standard and narrow gauge locomotives:*

| Weight per axle (weight on drivers divided by number of pairs of driving wheels). | Diameter of wheel center. | Minimum thickness, service limits. | |
|---|---|---|---|
| | | Road service. | Switching service. |
| | *Inches.* | *Inches.* | *Inches.* |
| 30,000 pounds and under........ | 44 and under..... | $1\frac{1}{4}$ | $1\frac{1}{8}$ |
| | Over 44 to 50..... | $1\frac{5}{16}$ | $1\frac{3}{16}$ |
| | Over 50 to 56..... | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| | Over 56 to 62..... | $1\frac{7}{16}$ | $1\frac{5}{16}$ |
| | Over 62 to 68..... | $1\frac{1}{2}$ | .......... |
| | Over 68 to 74..... | $1\frac{9}{16}$ | .......... |
| | Over 74.......... | $1\frac{5}{8}$ | .......... |
| Over 30,000 to 35,000 pounds.... | 44 and under..... | $1\frac{5}{16}$ | $1\frac{3}{16}$ |
| | Over 44 to 50..... | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| | Over 50 to 56..... | $1\frac{7}{16}$ | $1\frac{5}{16}$ |
| | Over 56 to 62..... | $1\frac{1}{2}$ | $1\frac{3}{8}$ |
| | Over 62 to 68..... | $1\frac{9}{16}$ | .......... |
| | Over 68 to 74..... | $1\frac{5}{8}$ | .......... |
| | Over 74.......... | $1\frac{11}{16}$ | .......... |
| Over 35,000 to 40,000 pounds.... | 44 and under..... | $1\frac{3}{8}$ | $1\frac{1}{4}$ |
| | Over 44 to 50..... | $1\frac{7}{16}$ | $1\frac{5}{16}$ |
| | Over 50 to 56..... | $1\frac{1}{2}$ | $1\frac{3}{8}$ |
| | Over 56 to 62..... | $1\frac{9}{16}$ | $1\frac{7}{16}$ |
| | Over 62 to 68..... | $1\frac{5}{8}$ | .......... |
| | Over 68 to 74..... | $1\frac{11}{16}$ | .......... |
| | Over 74.......... | $1\frac{3}{4}$ | .......... |
| Over 40,000 to 45,000 pounds.... | 44 and under..... | $1\frac{7}{16}$ | $1\frac{5}{16}$ |
| | Over 44 to 50..... | $1\frac{1}{2}$ | $1\frac{3}{8}$ |
| | Over 50 to 56..... | $1\frac{9}{16}$ | $1\frac{7}{16}$ |
| | Over 56 to 62..... | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| | Over 62 to 68..... | $1\frac{11}{16}$ | .......... |
| | Over 68 to 74..... | $1\frac{3}{4}$ | .......... |
| | Over 74.......... | $1\frac{13}{16}$ | .......... |
| Over 45,000 to 50,000 pounds.... | 44 and under..... | $1\frac{1}{2}$ | $1\frac{3}{8}$ |
| | Over 44 to 50..... | $1\frac{9}{16}$ | $1\frac{7}{16}$ |
| | Over 50 to 56..... | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| | Over 56 to 62..... | $1\frac{11}{16}$ | $1\frac{9}{16}$ |
| | Over 62 to 68..... | $1\frac{3}{4}$ | .......... |
| | Over 68 to 74..... | $1\frac{13}{16}$ | .......... |
| | Over 74.......... | $1\frac{7}{8}$ | .......... |
| Over 50,000 to 55,000 pounds.... | 44 and under..... | $1\frac{9}{16}$ | $1\frac{7}{16}$ |
| | Over 44 to 50..... | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| | Over 50 to 56..... | $1\frac{11}{16}$ | $1\frac{9}{16}$ |
| | Over 56 to 62..... | $1\frac{3}{4}$ | $1\frac{5}{8}$ |
| | Over 62 to 68..... | $1\frac{13}{16}$ | .......... |
| | Over 68 to 74..... | $1\frac{7}{8}$ | .......... |
| | Over 74.......... | $1\frac{15}{16}$ | .......... |
| Over 55,000 pounds............. | 44 and under..... | $1\frac{5}{8}$ | $1\frac{1}{2}$ |
| | Over 44 to 50..... | $1\frac{11}{16}$ | $1\frac{9}{16}$ |
| | Over 50 to 56..... | $1\frac{3}{4}$ | $1\frac{5}{8}$ |
| | Over 56 to 62..... | $1\frac{13}{16}$ | $1\frac{11}{16}$ |
| | Over 62 to 68..... | $1\frac{7}{8}$ | .......... |
| | Over 68 to 74..... | $1\frac{15}{16}$ | .......... |
| | Over 74.......... | 2 | .......... |

(*b*) When retaining rings are used, measurements of tires to be taken from the outside circumference of the ring, and the minimum thickness of tires may be as much below the limits specified above as the tires extend between the retaining rings, provided it does not reduce the thickness of the tire to less than 1⅛ inches from the throat of flange to the counterbore for the retaining ring.

(*c*) The minimum thickness for driving wheel tires shall be 1 inch for locomotives operated on track of 2-foot gauge.

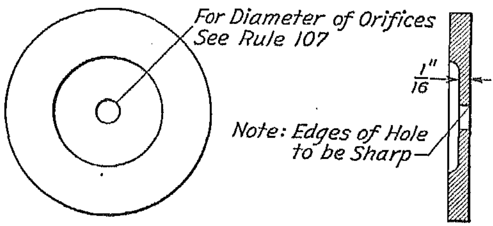


FIG. 14

TENDERS.

152. (*a*) *Tender frames.*—Tender frames shall be maintained in a safe and suitable condition for service.

(*b*) The difference in height between the deck on the tender and the cab floor or deck on the locomotive shall not exceed 1½ inches.

(*c*) The minimum width of the gangway between locomotive and tender, while standing on straight track, shall be 16 inches.

153. (*a*) *Feed water tanks.*—Tanks shall be maintained free from leaks, and in safe and suitable condition for service. Suitable screens must be provided for tank wells or tank hose.

(*b*) Not less frequently than once each month the interior of the tank shall be inspected, and cleaned if necessary.

(*c*) Top of tender behind fuel space shall be kept clean, and means provided to carry off waste water. Suitable covers shall be provided for filling holes.

154. *Oil tanks.*—The oil tanks on oil burning locomotives shall be maintained free from leaks. An automatic safety cut out valve, which may be operated by hand from inside and outside of cab, shall be provided for the oil-supply pipe.

155. (*a*) *Tender trucks.*—Tender truck center plates shall be securely fastened, maintained in a safe and suitable condition for service, and provided with a center pin properly secured. When shims are used between

truck center plates, the male center plate must extend into the female center plate not less than three-fourths inch.

(*b*) Truck bolsters shall be maintained approximately level.

(*c*) When tender trucks are equipped with safety chains, they shall be maintained in a safe and suitable condition for service.

(*d*) Side bearings shall be maintained in a safe and suitable condition for service.

(*e*) Friction side bearings shall not be run in contact.

(*f*) The maximum clearance of side bearings on rear truck shall be three-eighths inch, and if used on front truck three-fourths inch, when the spread of side bearings is 50 inches. When the spread of the side bearings is increased, the maximum clearance may be increased in proportion.

### THROTTLE AND REVERSING GEAR.

156. *Throttles.*—Throttles shall be maintained in safe and suitable condition for service, and efficient means provided to hold the throttle lever in any desired position.

157. *Reversing gear.*—Reversing gear, reverse levers, and quadrants shall be maintained in a safe and suitable condition for service. Reverse lever latch shall be so arranged that it can be easily disengaged, and provided with a spring which will keep it firmly seated in quadrant. Proper counterbalance shall be provided for the valve gear.

158. Upon application to the Chief Inspector, modification of these rules, not inconsistent with their purpose, may be made for roads operating less than five locomotives, if an investigation shows that conditions warrant it.

### FILING REPORTS.

159. *Report of inspection.*—Not less than once each month and within 10 days after inspection a report of inspection, Form No. 1, size 6 by 9 inches, shall be filed with the United States Inspector in charge for each locomotive used by a railroad company, and a copy shall be filed in the office of the chief mechanical officer having charge of the locomotive.

160. A copy of the monthly inspection report, Form No. 1, or annual inspection report, Form No. 3, properly filled out, shall be placed under glass in a conspicuous place in the cab before the locomotive inspected is put into service.

161. Not less than once each year, and within 10 days after required tests have been completed, a report of such tests, showing general condition of the locomotive, shall be submitted on Form No. 3, size 6 by 9 inches, and filed with the United States Inspector in Charge, and a copy

shall be filed in the office of the chief mechanical officer having charge of the locomotive. The monthly report will not be required for the month in which this report is filed.

Form No. 3 should be printed on yellow paper.

NOTE.—Samples of Forms Nos. 1 and 3, indicating exact size, color, weight, and grade of paper, will be furnished on application.

ACCIDENT REPORTS.

162. In the case of an accident resulting from failure, from any cause, of a locomotive or tender, or any appurtenances thereof, resulting in serious injury or death to one or more persons, the carrier owning or operating such locomotive shall immediately transmit by wire to the Chief Inspector, at his office in Washington, D. C., a report of such accident, stating the nature of the accident, the place at which it occured, as well as where the locomotive may be inspected, which wire shall be immediately confirmed by mail, giving a full detailed report of such accident, stating, so far as may be known, the causes and giving a complete list of the killed or injured.

NOTE.—Locomotive boilers and their appurtenances will be inspected in accordance with the order of the Commission, dated June 2, 1911.

Safety appliances on locomotives will be inspected in accordance with the order of the Commission, dated March 13, 1911.

Form No. 2.

Locomotive { Number ..........................
Locomotive { Initials ..........................

..........................................*Railroad*

## LOCOMOTIVE INSPECTION REPORT.

INSTRUCTIONS.—Each locomotive and tender must be inspected after each trip or day's work and report made on this form, whether needing repairs or not. Proper explanation must be made hereon for failure to repair any defects reported, and the form approved by foreman, before the locomotive is returned to service.

Inspected at........................., time.........m. Date ......................19

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Repairs needed:

..........................................................................................

..........................................................................................

..........................................................................................

..........................................................................................

..........................................................................................

..........................................................................................

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Condition of injectors..............................................Water glass ......................

Condition of gauge cocks ..............................................Brakes ......................

Condition of piston rod and valve stem packing..............................................

Safety valve lifts at........pounds. Seats at........pounds.

Main reservoir pressure,........pounds. Brake pipe pressure, ........pounds.

(Signature) ......................................

(Occupation) ......................................

The above work has been performed, except as noted, and the report is approved.

......................................
*Foreman.*

NOTE.—Additional items may be added to this form if desired.

# HEAT AND SUPERHEATERS

Serial 2504 Edition 2

## HEAT

### MEASUREMENT OF TEMPERATURE

**1. Heat and Cold.**—The terms *hot* and *cold* are commonly used to distinguish between a body that gives one the sensation of warmth and a body that gives the sensation of cold. However, an object only seems warm when it is warmer than the human body, and cold when cooler than the body. Therefore, the senses are not a true indication of the warmth and the coolness of an object. Actually, all objects are heated, except at a certain temperature to be explained later. This means that the difference between an object that seems warm and one that seems cold is that the latter is heated to a lesser degree than the former. Hence, when taken in this sense, the term cold means a certain absence of, but not an entire absence of, heat. Water when boiling is much hotter than a block of ice, but the ice also contains heat.

The natural heat that the surface of the earth and all bodies on the earth possess, is due to the heat received from the sun; that is, solar radiation is responsible for the heated condition of the earth.

**2. Theory of Heat.**—It is supposed that all substances are composed of a large number of particles, called atoms, which are so small that they cannot be seen even by the aid of the most powerful microscope. Atoms, which in turn are made up of

still smaller particles called electrons, tend to form groups known as molecules.

The position of the molecules with respect to one another depends on whether the substance is a solid, a liquid, or a gas. With a solid like a piece of iron, it is supposed that, if it were possible to see the molecules, they would be found packed closely together as shown in Fig. 1. With a liquid such as water, the molecules, each of which is composed of three atoms as shown in Fig. 2, are supposed to be farther apart, whereas with a gas, the molecules are rather widely separated, as in Fig. 3.

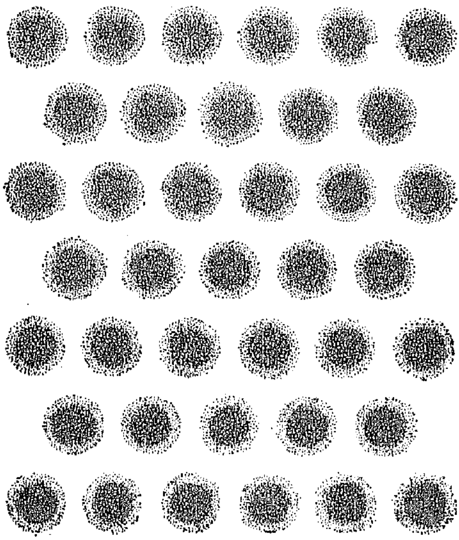


FIG. 1

There is a certain force or attraction between the molecules of a body as well as between the atoms that make up the molecules, which holds them together and causes solid bodies to retain their shape. This attraction is greatest in solids, is less in liquids, and is the least in gases. This lessening of the attraction between molecules is shown by their positions in Figs. 1, 2, and 3, and accounts for the hardness of a solid and for the freedom of movement of the molecules of liquids and gases.

Each molecule of a solid or a liquid body, such as in Figs. 1 and 2, is in continual motion. However, with a solid, the mole-

cules being closer together, their motion is less violent. This motion is called vibration, because it takes place through a very

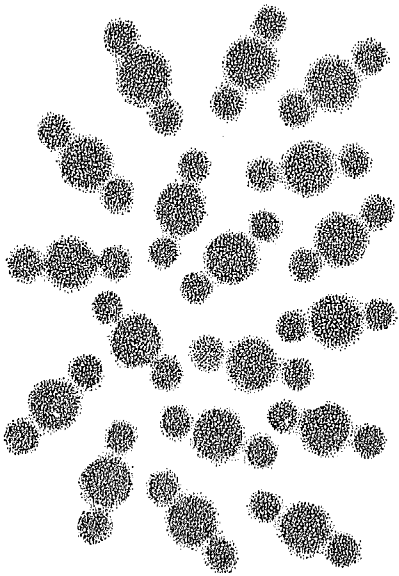


FIG. 2

short distance and is then reversed. In the case of a gas as in Fig. 3, the motion is different; each molecule flies practically

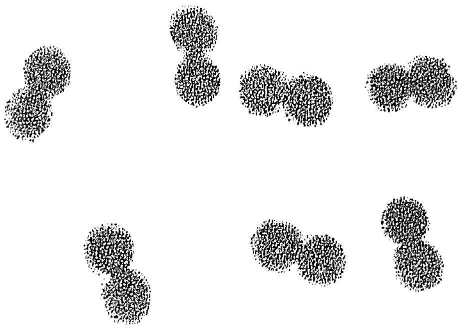


FIG. 3

in a straight line until it encounters another flying molecule. When this occurs there is a rebound and then another flight.

**3. Definition of Heat.**—The term *heat* is applied to the ceaseless movement of the molecules of which any body or substance is composed, although, strictly speaking, it is the energy of the atomic or molecular motion, by which is meant the ability of this motion to do work, that constitutes the heat of a body. Heat is therefore a condition or state of the molecules that make up any substance. The distinction between molecules, atoms, and electrons is not important in a general discussion of heat, since it is possible that all of these particles share in the motion.

The more rapidly the molecules vibrate, the hotter the body will be; conversely, the slower the movement of the molecules, the less hot, or the cooler, the body will be. Bodies, the molecules of which are vibrating rapidly enough, give one the sensation of warmth, and a body, the molecules of which are vibrating less rapidly, transmits the sensation of coolness, cold, or extreme cold, depending on the rate of vibration. However, as long as there is any movement of the molecules, a body possesses heat, even though it may seem excessively cold to the touch. As explained farther on, the movement of the molecules is supposed to stop at a temperature of 492° F. below the freezing point; the body then has no heat.

Confusion often results from the fact that the term heat is used with two different meanings. Ordinarily, the term is applied to the sensation received from a warm or a hot body; also, the term is applied to the ceaseless movement of the molecules of the body that is responsible for the sensation of heat. It is with this latter meaning that the term heat is here to be regarded.

The assertion that a body contains heat is also misleading, as the impression is given that heat is a tangible substance, instead of being a condition of the molecules of the body. Such a statement should be regarded as merely a convenient expression to indicate that the molecules of a body are vibrating to a greater or a lesser degree.

**4. Temperature.**—The term temperature is used to indicate how hot or cold a body is. Also, as the degree of heat or cold is dependent on the speed of the molecules that compose the

body, the temperature is a measure of the speed with which they are vibrating. A rise or a fall in temperature indicates, respectively, an increase or a decrease in molecular speed. Temperature is measured by an instrument called a thermometer, one type of which is shown in Fig. 4. It consists of a glass tube closed at both ends, and with a bulb at the lower end. The bulb and the lower end of the tube are filled with mercury.

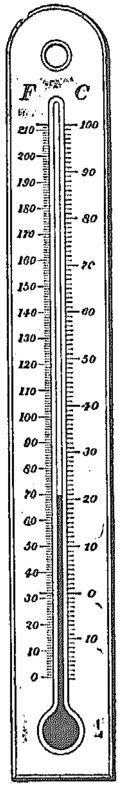


FIG. 4

The theory of the operation of the thermometer is as follows: When the thermometer is placed, say, in warm water, the vibrations of the molecules of water are communicated to the glass and thence to the mercury, and the molecules of both will finally begin to vibrate at about the same rate as the molecules of water. As the velocity of the molecules of mercury increases, they move farther apart and the mercury is said to expand. A reverse effect will occur if the thermometer is placed in cold water; the mercury will then contract. This expansion and contraction causes the mercury column to rise and fall, and, since equal changes in temperature make the column rise or fall equal distances, the graduations on the scale are made equal throughout. Therefore, a thermometer indicates the rate of vibration of the molecules of a body and this in turn is an index of its temperature.

The thermometer shown in Fig. 4 has two scales. The scale at the left, marked *F*, in combination with the glass tube, forms a Fahrenheit thermometer, which is the one commonly used; the scale *C* on the right forms, in combination with the glass tube, a centigrade thermometer.

**5. Graduating a Thermometer.**—The graduations on the scale of a thermometer are obtained as follows: First, the thermometer is placed in melting ice, and the point to which the mercury column falls at atmospheric pressure is marked and called the *freezing point*. The thermometer is next placed in

steam that is escaping from an open vessel and the point to which the mercury rises in the tube is marked and called the *boiling point*. These are two fixed points; that is, the mercury column will always register these same points when the thermometer is placed in melting ice or in steam under the conditions just mentioned.

The freezing point marks the temperature at which, under atmospheric pressure, water freezes and forms ice; the boiling point marks the temperature at which water boils and forms steam when subjected to atmospheric pressure.

Having these two fixed points, the distance between them is divided into equal parts, the number of divisions depending on whether the scale is for a Fahrenheit or a centigrade thermometer.

**6. Fahrenheit Thermometer.**—The Fahrenheit thermometer is made by dividing the distance on the scale between the freezing and the boiling points into 180 equal divisions called *degrees*. The freezing point is marked 32, and the boiling point 212. From the freezing point downwards, 32 divisions are marked off, and the lowest one is marked 0; this is called the *zero point* of the scale. The graduations may be extended above the boiling point or below the zero point as desired.

Instead of writing the word *degrees* after each reading of temperature, it is customary to represent it by the symbol °, which is placed above and to the right of the figures. Also, the word *Fahrenheit* is usually represented by the letter F. Thus, 32° F. means the same as though it were written "32 degrees Fahrenheit"; and 8° F., the same as "8 degrees Fahrenheit." In this thermometer there are 212 divisions between the zero point and the boiling point and $212-32$, or 180, degrees between the freezing point and the boiling point.

**7. Centigrade Thermometer.**—In the centigrade thermometer, the freezing point is marked 0, and the boiling point 100, the distance between the two being divided into 100 equal divisions. As in the Fahrenheit scale, the divisions may be carried above the boiling point and below the zero point. The word

*centigrade* is usually abbreviated and written C., as, for example, 10° C., 28° C., etc.

8. **Thermometer Readings.**—Beginning with 0°, the divisions on both the Fahrenheit and centigrade scales are numbered 1, 2, 3, 4, etc., both above and below the zero point. Therefore, in giving the lower readings of a thermometer, it is necessary to state the number of degrees and whether they are above or below zero. To distinguish temperatures below zero from those above, a minus sign is always placed before the former. Thus, 12° means 12° above zero on both scales, whereas −12° means 12° below zero.

9. **Absolute Temperature.**—When the Fahrenheit scale was devised, the zero point of the thermometer was placed 32° below the freezing point, as that was the lowest temperature that could then be obtained, and it was supposed that it was impossible to obtain a lower one. From the results of experiments, however, it has been concluded that at 460° F. below zero, or 492° F. below the freezing point, there is absolutely no vibration of the molecules of any body, and consequently the body has no heat. This point is therefore called the *absolute zero* and all temperatures reckoned from this point are called *absolute temperatures.* Absolute zero has never been reached, although temperatures closely approaching it have been obtained.

10. **Pyrometers.**—Mercurial thermometers cannot be used for the measurement of extremely high temperatures such as exist in furnaces. The instruments used for work of this character are called pyrometers. The type used to determine the temperature of the superheated steam in locomotive practice makes use of the thermocouple principle, by means of which an electric current proportionate to the difference in temperature between the hot and cold junctures of the couple is generated. The indicator itself contains a millivoltmeter actuated by the current generated at the thermocouple and moves a pointer on the dial, thus indicating the actual temperature of the steam.

11. **Quantity of Heat.**—It has already been stated that heat is the term applied to the vibration of the molecules of a

body; thus, heat is a condition of matter. The term quantity of heat is therefore not strictly correct, because it implies that heat is a substance and is something tangible. However, *quantity of heat* and *amount of heat* are terms that are found in all discussions on this subject, and although somewhat misleading, they are very convenient terms to use.

A study of the following will give an idea of what is meant by quantity of heat: Let it be assumed that a pint of water and a quart of water are each heated over a gas flame of the same size, thereby insuring that both are subjected to the same heat. It will be found that the pint of water will reach the boiling point first, and that heat must be applied to the quart of water for some time afterwards before the water will commence to boil. With the water in both boiling, a thermometer inserted in each one will indicate the same temperature. But heat has been applied for a longer time to raise the quart of water to the boiling point, hence it is said to contain a greater amount or quantity of heat than the pint of water. The explanation is that it necessarily requires more heat to put the larger number of molecules in the quart of water in the same state of vibration as the smaller number of molecules in the pint of water. That the temperature of both is the same is an indication that the molecular vibration of water is equal in both vessels.

Therefore, of two bodies of the same temperature and under the same pressure, the one that has the greater number of molecules, that is, the one that weighs the more, will contain the more heat. A thermometer alone is no guide in determining the quantity of heat that a body contains; this instrument only indicates the rate at which the molecules are vibrating, or the temperature. To determine the quantity of heat, not only the temperature but also the weight of the water must be known.

**12. British Thermal Unit.**—Just as a pound has been taken as a unit of weight, and a foot as a unit of length, so a unit for measuring the quantity of heat has also been established. An increase in the temperature of one pound of pure water from 62° F. to 63° F., or one degree, is taken as the quantity of heat unit. That is, the quantity of heat already in one pound of

water is increased by one unit when the temperature of the water has been increased as stated. The name given to the quantity of heat unit is the British thermal unit, abbreviated B. t. u.

In defining the unit of heat, it is necessary to specify the temperature of the water, because the amount of heat necessary to raise one pound of water through one degree varies slightly with the water at different temperatures. However, the variation is so slight that, for most practical problems, the unit of heat may be taken as the quantity of heat required to raise the temperature of one pound of water one degree without reference to any particular temperature.

It has already been stated that any substance contains some heat except at absolute zero, or 492° F. below the freezing point. However, when calculating in heat units the quantity of heat a body contains, it is assumed that water at the freezing point, or at 32° F., contains no heat. Therefore, if the temperature of one pound of water at 32° F. is increased to 33° F., the water is said to contain a quantity of heat equal to one unit, or one B. t. u.; if increased from 33° F. to 34° F., two heat units, etc. If the water is heated from 32° F. to 212° F., or to the boiling point, the water would be raised $212-32$ or 180 degrees; hence one pound of water would contain a quantity of heat equal to 180 B. t. u., or one B. t. u. for each degree the temperature of the water has been increased. One hundred pounds of water at the boiling temperature would contain $100 \times 180$ or 18,000 B. t. u.

**13. Determining Heat Units in Fuels.**—Having selected a definite quantity of heat unit; namely, the heat required to raise the temperature of one pound of water one degree Fahrenheit, it is possible to determine the number of heat units in a sample of coal. This is done by so burning the coal that its heat is communicated to a certain weight of water; then, by observing the rise in temperature, the heating value of the coal in B. t. u. can be readily calculated. A device for determining the heating value of coal is known as a *coal calorimeter.*

The following gives, in a general way, the arrangement and operation of such an apparatus; a detailed explanation is beyond

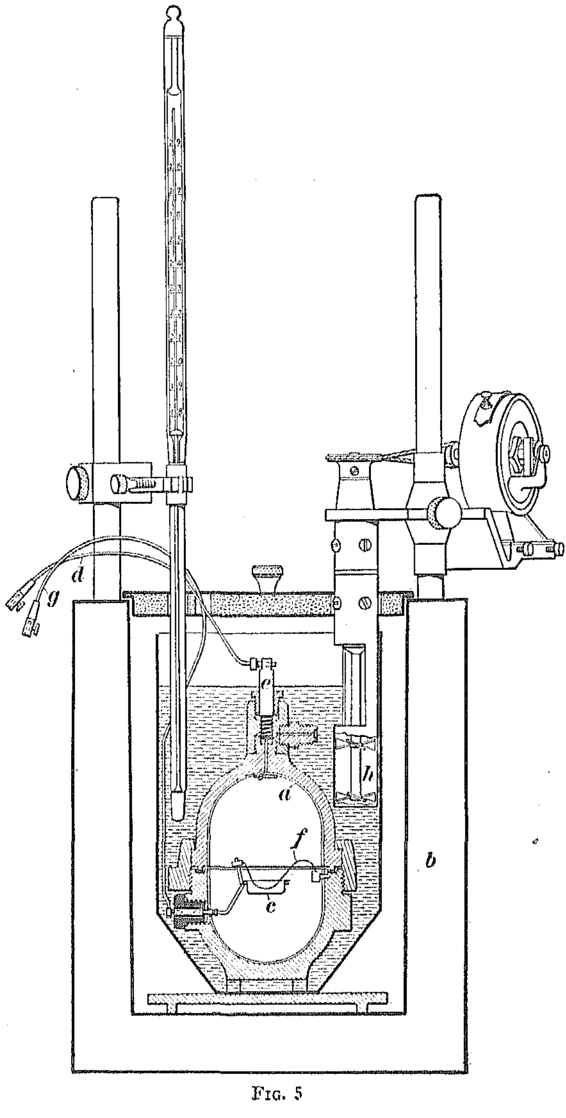



FIG. 5

the scope of this paper. As shown in Fig. 5, the calorimeter consists of a strong steel receptacle *a*, called a bomb, that is immersed in water in a tank *b*. The sample of coal is placed within the bomb on a nickel or platinum pan *c*. The bomb is charged with pure oxygen at a high pressure through the piping *d* and the valve *e*. When the pressure in the bomb rises to about 300 pounds, the oxygen supply is cut off from the piping, and the valve *e* is then closed. The coal is ignited by means of the fuse wire *f*, which is heated by passing an electric current through the wire *g*; and, owing to the presence of the oxygen, the sample will be completely burned.

The weight of the water in which the bomb is immersed is known, as well as the weight of the coal. Then, with the increase in the temperature of the water indicated by the thermometer shown, it becomes an easy matter to calculate the heating value of the coal.

For example, it is assumed that the sample of coal weighs .004 pound, that the water weighs 4 pounds and that the temperature increases 12° F. The quantity of heat absorbed by the water is then $12 \times 4$ or 48 B. t. u. However, only .004 pound of coal was burned; if a whole pound were burned, the heat produced would have been equal to $\frac{48}{.004}$ or 12,000 B. t. u.; this, then, is the heating value of the coal.

The stirring device *h*, driven by the motor shown, is to keep the water agitated and thus secure as uniform a temperature throughout the water as possible. The tank is usually surrounded with a jacket having a vacuum wall, so that there will be a minimum exchange of heat between the tank and its surroundings.

**14. Sources and Generation of Heat.**—There are two main sources of heat: one source is the heat obtained from the burning of coal, gas, and oil or its distillates, gasoline and kerosene; and the other source is water power, from which electricity is generated for heat and light. As yet no means has been found to make available for commercial use the heat received from the sun.

The generation of heat in the first instance is brought about by the union of the oxygen of the air with the elements, carbon and hydrogen, which make up the larger part of such fuels as wood, coal, and oil. When the fuel is heated sufficiently, the oxygen unites with the carbon and the hydrogen to form products that are entirely different from those that entered the union, and burning, or combustion, is then said to have taken place. Burning, or the union of the oxygen with the carbon and the hydrogen, is accompanied, for reasons not yet fully understood, by an intense vibration of molecules, or by heat.

**15. Heat of Combustion.**—The proportion of carbon and hydrogen in the fuel determines the quantity of heat that is generated during combustion. Hydrogen when burned evolves over four times as much heat as carbon, hence fuels that are rich in hydrogen, such as oil and gasoline, have a much higher heat producing value than coal, in which the carbon content largely exceeds the hydrogen.

The quantity of heat obtained from the burning of one pound of hydrogen is 62,000 B. t. u.; that is, enough heat is generated to raise the temperature of 62,000 pounds of water one degree. The burning of a pound of good coal produces about 14,500 B. t. u., or enough heat to raise 14,500 pounds of water one degree.

The burning of carbon may be complete or incomplete, depending on the proportion of oxygen which unites with the carbon. If one part, by volume, of carbon unites with two parts of oxygen, the resulting product is carbon dioxide. The combustion is then said to be complete, because carbon dioxide cannot be burned. For every pound of carbon that is so burned, 14,500 B. t. u. is generated. If one part, by volume, of carbon unites with only one part of oxygen, the resulting product is carbon monoxide. Combustion is then said to be incomplete, because more oxygen might have been combined with the carbon, and because the carbon monoxide is also capable of being burned. Only 4,400 B. t. u. is produced when carbon burns to carbon monoxide.

### TRANSMISSION OF HEAT

**16. Transfer of Heat.**—The term *transfer of heat* means the transfer of the vibration of the molecules of one body to another body, thereby causing a vibration of its molecules. Heat may be transmitted from one place to another in three different ways; namely, by conduction, by convection, and by radiation or by a combination of two or more of these methods.

**17. Conduction.**—Conduction is the transfer of heat from a place of higher temperature to a place of lower temperature in the same body without motion of the body as a whole, or from one body to another with which it is in contact. Thus, if one end of a short iron rod is placed in a hot fire, the entire rod will soon become warm, owing to the fact that the vibration of the molecules in the heated part of the rod is communicated to the others throughout the length of the rod.

**18. Convection.**—Convection is the transfer of heat by motion of the particles of the heated substance. The transfer of heat by convection occurs only in liquids and gases. For example, if heat is applied to the bottom of a vessel that contains water, the water in contact with the bottom becomes heated and rises, while the colder water above descends. A circulation is thus set up by which the heated portions of the water continually carry heat to other points in the vessel. Thus, by the process of convection, the entire mass of water at length becomes heated.

**19. Radiation.**—The heat from an electric globe can be felt when the hand is held beneath it. As the hand is not touching the globe, the heat experienced is not due to conduction, neither is it due to convection, because the air which would carry the heat, rises when heated. Heat is said to be transferred by radiation when it is carried across a space without the aid of any material substance; such heat is called *radiant heat*. As yet, science is unable to offer an explanation of the transfer of heat by radiation.

Examples of radiant heat are very common. A person standing in front of a fire but at some distance from it feels a sensa-

tion of warmth which is not due to the temperature of the air, because if a screen is placed in front of the fire, the sensation immediately ceases. The heat from the sun reaches the earth by radiation.

The transfer of heat by conduction and convection is very slow, whereas with radiation it is very rapid. Radiant heat travels at the same speed as light, or about 186,000 miles a second.

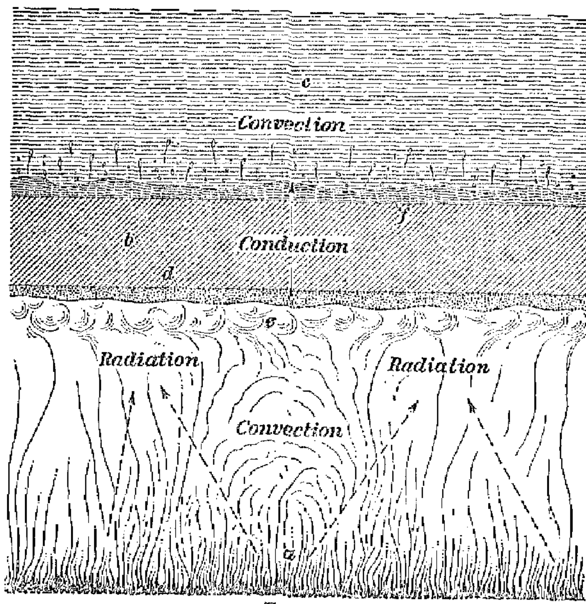



FIG. 6

**20. Heat Transfer in Boiler.**—As shown by the diagram in Fig. 6, the transfer of heat from the burning fuel to the water in a boiler is accomplished by radiation, conduction, and convection. The burning of the fuel at *a* gives an incandescent fire from which heat is radiated against the sheet *b* of the boiler. The radiant heat heats the surface of the sheet, then the whole sheet is heated throughout by conduction. The hot gases that arise from the fire heat the gases in the firebox by convection. These hot gases then come in contact with the sheet and also heat it by conduction.

The water in direct contact with the sheet is heated because the sheet has already been heated by conduction. The water then rises, cooler water takes its place, and the heat is carried through the whole body of the water *c* by convection, owing to the rising of the warm water currents.

The scale *f* that collects on the water side retards the passage of heat from the sheet to the water. To promote the rapid transmission of heat, the sheet should be kept as free as possible from scale. In actual operation, a coating of soot *d* collects on the fire side of the plate and retards the flow of heat from the hot gases *e* to the plate.

If the sheet is too thick, the conduction of heat through it will be slow; hence the heat will not be absorbed as rapidly by the water, and the firebox side of the sheet will become overheated. For this reason the sheets of the firebox are not made thicker than $\frac{3}{8}$ inch or $\frac{7}{16}$ inch.

## FORCE AND WORK

**21. Force.**—Force is defined as that which causes or tends to cause motion. Any push or pull exerted against a body, whether sufficient to move it or not, is an example of force. Force is exerted when any object is moved from one place to another.

Examples of force are very common. A locomotive is exerting force when pulling a train, and the steam in the cylinders of the locomotive is exerting force on the pistons and is causing them to move.

Another example of force is that of gravity. The force required to lift or to sustain an object in the hand is usually ascribed to its weight. In reality it is the force of gravity or the attraction of the earth upon the object, tending to pull it back to the earth, that is responsible. In the absence of the force of gravity, an object would not have weight, hence the weight of a body is merely a measure of the pull or force that gravity is exerting upon it.

**22. Work.**—Work is said to be performed when the body to which force is applied, is moved. Thus, work is performed

when an object is raised from the floor and placed on the table, because a great enough force is applied to the object to move it. Therefore, two conditions are necessary before work can be performed; first, there must be force, and second, there must be motion, and motion implies distance.

Since work is a combination of force and distance, a convenient unit for the measurement of work can be established by combining the units of force and distance. The unit for measuring force is the pound, and the unit for measuring distance is the foot; hence, the unit of work is taken as the foot-pound. An amount of work equal to one foot-pound is performed when one pound is raised one foot, or when a force of one pound is applied through a distance of one foot. A weight of 100 pounds lifted 10 feet would represent an amount of work equal to $100 \times 10 = 1{,}000$ foot-pounds. A locomotive that developed a draw-bar pull of 20,000 pounds when moving a train 1,000 feet has performed work equal to $20{,}000 \times 1{,}000$ or 20,000,000 foot-pounds.

In all cases, the work performed is equal to the force multiplied by the distance through which the force acts or stated as a formula

$$\text{work} = \text{force} \times \text{distance}$$

**23. Rate of Doing Work.**—The time element, or the slowness or quickness at which work is done, does not enter in any way into calculations involving the amount of work performed. For example, the amount of work performed in raising 500 pounds of wheat 2 feet is 1,000 foot-pounds, and is the same whether the wheat is raised in 1 minute or in 5 hours. A child could raise the wheat, lifting a little at a time, and he would do as much work as a man who could raise 100 pounds at a time. However, the time consumed by the child in doing the work will be much greater than that required by the man.

The term *rate of doing work* means the amount of work done in a unit of time, and is calculated by dividing the amount of work done by the time in minutes required to do it, or written as a formula

$$\text{rate of doing work} = \frac{\text{force} \times \text{distance}}{\text{time in minutes to do work}}$$

As distance in feet divided by time in minutes is equal to velocity, the foregoing formula may also be written as follows:

$$\text{rate of doing work} = \text{force} \times \text{velocity}$$

The rate at which a locomotive is doing work with a drawbar pull of 20,000 pounds and moving 1,760 feet per minute, or 20 miles per hour, is equal to $20{,}000 \times 1{,}760 = 35{,}200{,}000$ foot-pounds per minute.

24. **Unit of Rate of Doing Work.**—The rate of doing work is taken as the number of foot-pounds of work done in one minute. The unit of rate of doing work is the horsepower and represents the performance of 33,000 foot-pounds of work in one minute. With so many foot-pounds to represent a horsepower, the solution of problems involving horsepower will result in small numbers.

When applied to a locomotive, the unit of rate of doing work is generally referred to as the drawbar horsepower. To calculate the drawbar horsepower, it is merely necessary to multiply the force or the pull at the drawbar by the velocity and divide by 33,000, or stated as a formula

$$\text{rate of doing work in horsepower} = \frac{\text{force} \times \text{velocity}}{33{,}000}$$

EXAMPLE.—The drawbar pull as shown by a dynamometer car, with a locomotive moving at 25 miles per hour is 24,000 pounds. What drawbar horsepower is the locomotive developing?

SOLUTION.—A speed of 25 mi. per hr. is 2,200 ft. per min., hence the rate at which work is being done is $\frac{24{,}000 \times 2{,}200}{1} = 52{,}800{,}000$ ft.-lb. per min. The drawbar horsepower is then equal to $\frac{52{,}800{,}000}{33{,}000} = 1{,}600$ hp. Ans.

The tractive force of a locomotive is calculated by the use of the formula, work = force × distance. To illustrate, it is here assumed that a locomotive has cylinders of a diameter of 26 inches, a stroke of 28 inches, driving wheels of a diameter of 63 inches, and a steam pressure of 200 pounds. The first step is to find the amount of work that is being performed at the

crankpin on one side. This is equal to the average pressure on the piston multiplied by the distance through which the force acts for one turn of the wheels. This distance is equal to twice the stroke.

The average pressure on the piston is found by multiplying its area, or 530.9 square inches, by 85 per cent. of the boiler pressure, or 170 pounds; hence the average pressure on the piston is equal to 90,253 pounds. This force acts through 56 inches, or twice the stroke. The work performed at the crankpin is then equal to 90,253×56 or 5,054,168 foot-pounds.

With the amount of work performed at the crankpin known and the distance through which this force acts, or the circumference of the wheel, also known, the force developed at the rim of the wheel, or the tractive force, is equal to 5,054,168 divided by 197.9, the circumference of the wheel in inches, or 25,539 pounds. However, only one side of the locomotive has been taken into account in the foregoing; with both sides considered the tractive force becomes equal to 25,539×2 or 51,078 pounds.

## RELATION BETWEEN HEAT AND WORK

**25. Mechanical Equivalent of Heat.**—If the hand is rubbed vigorously on a table for a few minutes, a sensation of warmth is obtained. Also, a bar of iron will become heated when hammered rapidly with a hammer, because this action increases the rate of vibration of the molecules of the bar. For the same reason, or owing to increased molecular vibration, the journals of cars unless kept well oiled will soon heat to such an extent as to ignite the packing. In all the above cases, work is being performed, therefore a relationship exists between work and heat; that is, work can be changed into heat.

Heat can also be changed into work, because the heat, or the intense vibration of the molecules that accompanies the combustion of fuel in a locomotive firebox, is changed into work in the cylinders. The vibration of the molecules in the firebox is communicated to the water in the boiler with the result that particles of water called steam are expelled. The vibration of these particles in turn causes a pressure to be exerted on the pistons and moves them. Therefore, the heat, or the vibration

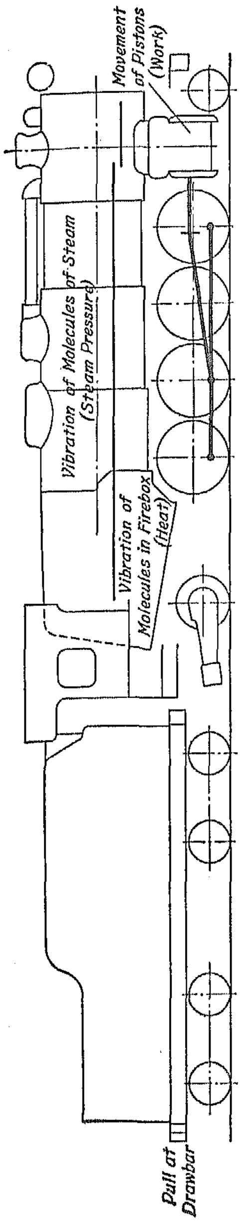



Fig. 7

of the molecules, that accompanies combustion appears finally as a pull at the drawbar. In other words, the firing of a scoop of coal into the firebox is but the beginning of a series of actions and reactions that end with the delivery of power at the drawbar. The foregoing is shown graphically in Fig. 7.

The steam locomotive is then a heat engine, or an engine in which heat is converted into work through the medium of water.

**26.** A definite relation has been established between the unit of heat, or British thermal unit, and the unit of work, or the foot-pound. Experiments have shown that one British thermal unit is equivalent of 778 foot-pounds of work. This means that the increase in the vibrations of the molecules of 1 pound of water when raised from 62° F. to 63° F., if wholly converted into work, would raise 1 pound 778 feet high or 778 pounds 1 foot high. The quantity 778 is called the mechanical equivalent of heat.

The first experiment to determine with a fair degree of accuracy the relationship between heat and work was performed by Joule. By means of the apparatus shown in Fig. 8 he found that one pound of water was increased in temperature one degree by the work done during the descent of 772 pounds one foot. By an

arrangement of drums and pulleys, the weight *w*, in falling, was made to operate the paddles *p* in the vessel *v*, which was filled with water. The work performed by the weight in falling was all expended in churning the water, except the small quantity used in overcoming the friction of the moving parts. A very delicate thermometer *t* showed that the action of the paddles raised the temperature of the water, and since no heat was applied to the water in any other way it was evident that

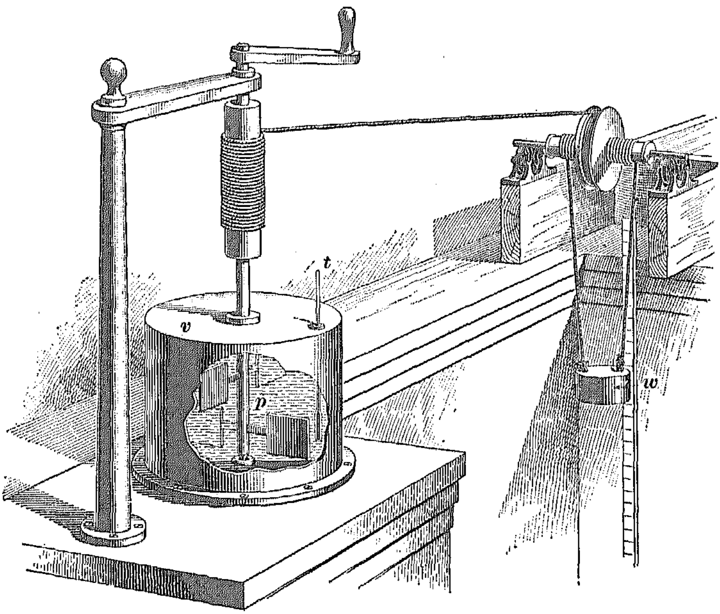



FIG. 8

the rise in temperature was due directly to a transformation of work into heat. Although Joule's experiment showed that one British thermal unit was equivalent to 772 foot-pounds of work, later and more accurate experiments showed this value to be 778.

**27. Conversion of Heat and Work Units.**—The quantity 778, or the mechanical equivalent of heat, is used when it is desired to change foot-pounds of work into heat units or heat units into foot-pounds of work. To change heat units into foot-pounds, the number of heat units should be multiplied by 778

and to change foot-pounds into heat units, the foot-pounds should be divided by 778.

EXAMPLE.—A pound of a certain coal has a heating value of 12,500 B. t. u. How many foot-pounds of work would be performed if it were possible to convert all of this heat into work?

SOLUTION.—The number of ft.-lb. of work can be found by multiplying the total number of heat units by the mechanical equivalent of heat; thus, $12{,}500 \times 778 = 9{,}725{,}000$ ft.-lb. Ans.

EXAMPLE.—What equivalent amount of heat is represented by 266,067 foot-pounds of work?

SOLUTION.—The number of heat units can be determined by dividing the number of ft.-lb. of work by 778; thus, $266{,}076 \div 778 = 342$ B. t. u.

It is important for a fireman to know the relation between heat and work because he will then realize more fully the importance of skilful firing. As the heat developed by the burning of the fuel in the firebox ultimately appears as a pull at the draw-bar, or as work, the cost at which the work is being done will depend on the amount of heat evolved from each pound of coal burned. If the firing is done carelessly, large amounts of the coal will escape unburned or it may merely burn to carbon monoxide and, while the locomotive may be performing the same amount of work as if the firing were being done skillfully, yet the cost of the work in the former instance will be much higher. The amount of coal used over and above that necessary to perform the work represents waste. The purpose of fuel-conservation campaigns on railroads is to stress the fact that heat and work are convertible and that the cost of the work will decrease according as more of the heat in each scoopful of coal is changed into work by skilled firing.

28. **Machines for Changing Heat Into Work.**—With steam as a medium, there are only two methods whereby heat can be converted into work: (1) by means of a suitable arrangement of cylinders and pistons as with the reciprocating steam engine; (2) by means of the steam turbine.

With the steam engine, the vibration of the molecules, or the heat that occurs during the burning of the fuel, is communicated to the water in the boiler and results in a vibration of the mole-

cules of the water. The vibration of the water molecules increases until finally the attraction that holds them together is overcome to such an extent that some of them are expelled from the liquid at a high velocity. These rapidly moving molecules of water are called *steam*.

The continual bombardment of the interior of the boiler by the countless number of steam molecules that are finally expelled as the water continues to be heated, causes a thrust against the sheets; that is, the sheets will have an outward pressure acting upon them.

When the throttle is opened, the pressure exerted by the heat, or the vibration of the steam molecules in the boiler, will be transferred to the cylinders as well, and will move the pistons. The locomotive will then move and exert, through its drawbar, a pull on the train. The movement of the pistons should not be ascribed to the pressure of the steam but to the heat, or the vibration of the molecules of the steam that causes the pressure.

The vibration of the molecules that accompanies the burning of the fuel in the firebox is called heat, and the movement of the train by the locomotive is known as work. It is clear, therefore, that the heat generated by the burning fuel is finally converted into work at the drawbar.

The steam turbine, unlike the reciprocating engine with its arrangement of cylinders and pistons, converts heat into work in a different manner. This type of engine uses a series of steam nozzles for this purpose. Owing to its compact design and great economy, the turbine engine is in almost universal use in large power plants.

**29.** The arrangement of the cylinder and piston causes heat to be converted into work because the cylinder confines the steam molecules and causes their vibration to be imparted to the piston, thereby causing it to move. The steam nozzle is an extremely ingenious device because it accomplishes the transformation of heat into work without the use of any moving parts whatever. This device converts heat into work by changing heat, or the random and aimless movement of the steam molecules, into a definite movement in one direction at a high velocity.

The velocity of the steam is increased about eight times. This stream of molecules will develop a high pressure when directed against the blades of a turbine wheel, and will cause it to revolve. Therefore, the steam nozzle converts heat into work because it causes the steam molecules to travel faster.

The tube is so shaped that it diverges or widens toward the outlet. Such a construction causes a gradual expansion of the steam with a corresponding reduction in its temperature, or in the vibration (or to-and-fro motion) of its molecules and in an increase in their velocity, or their movement in a straight line, forward.

This may be more easily understood by considering the tube as being divided into a great number of zones, *a*, *b*, *c*, etc., Fig. 9, in which, owing to their gradually increasing cross-sectional area, the temperature, and consequently the pressure, of the

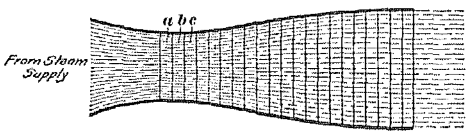



FIG. 9

steam are progressively lowered toward the outlet. This results in the steam particles passing from zone to zone at an ever increasing velocity. It can be seen, therefore, that the nozzle gradually transforms the vibration of the steam particles, that is, transforms the heat into a forward movement of the steam particles at a high velocity, or into work.

The steam nozzle of an injector is similar to the steam nozzle of a turbine; the high velocity of the steam is imparted to the water in the combining tube but, owing to the low pressure of the steam, the water exerts little pressure against the sides of the tube. The required water pressure is obtained by reducing the velocity of the water by the delivery tube. The pressure of the water is then raised high enough to open the boiler check-valve.

**30.** With the gasoline engine, an arrangement of cylinders and pistons is used; the transformation of heat into work is accomplished by heating or setting into rapid vibration the mole-

cules of gases by the combustion of gasoline vapor in the cylinders. A small quantity of gasoline vapor mixed with the correct amount of air to insure proper combustion is drawn into a cylinder during one stroke of the piston. On the return stroke, the mixture is compressed and is then ignited by a spark. The combustion that results occurs so quickly that it is termed an explosion, and the gases generated are very hot, or their molecules are in intense vibration, hence they exert a high pressure on the piston.

Owing to the compression of the mixture prior to combustion, the paths of the particles after combustion are shortened; therefore the pressure obtained is higher than otherwise.

## STEAM

**31. Definition.**—Steam is molecules of water that have been expelled from it by boiling, or it is water that has been changed into the gaseous state by the application of heat.

When heat is applied to water, the first effect is to raise the temperature of that part of the water in contact with the vessel in which it is being heated. The heated water then rises and the cooler water descends to take its place. The circulation thus set up causes the whole body of water to become heated and the rate of vibration of the molecules will increase as the temperature rises. Finally, a point is reached at which the vibration of the molecules becomes so great that some of them fly up into space above the surface of the water. The point at which this occurs is called the boiling point, and the molecules of water that are expelled are called steam.

It is of interest to note that the three different states in which water exists are due to the rate of vibration of its molecules. With water in the form of steam, the molecules are in rapid vibration and hence are widely separated. With a lesser rate of vibration, the molecules are less widely separated and they form a liquid; and with a still lesser rate of vibration, the molecules are in such intimate contact that a solid, or ice, is formed.

**32. Theory of Steam Pressure.**—The theory of steam pressure has already been given to some extent in Art. 31, and little

further explanation is necessary. When water is heated in a confined space like a locomotive boiler, the expulsion of the steam molecules from the water will continue until at last the space above the water is filled with countless particles that strike, and hence exert a pressure against, the interior of the boiler and also on the surface of the water. This condition is shown in Fig. 10, in which the steam molecules are indicated by black dots and their paths by dotted lines. Steam pressure is thus seen to be the result of the incessant movement of innumerable molecules of steam.

The gradual increase that occurs in the steam pressure as the water in the boiler continues to be heated is explained as follows: The molecules of steam, as they strike against and exert a pressure on the interior of the boiler, also return and strike against and exert a pressure on the surface of the water. The result is that, before any new molecules can be expelled from the water, their vibration must be increased, or the temperature of the water must be increased; hence, when they finally leave the water as steam, their velocity and the pressure they will exert will be greater. The increase in pressure will again make the expulsion of the steam particles from the water more difficult, and when they are expelled they in turn will exert a greater pressure. The result will be a gradual increase in the steam pressure as the water continues to be heated, until the pressure increases to that at which the safety valve is set. The ordinary boiler pressure in locomotive practice is 200 pounds, hence the vibration of the molecules of steam is great enough to exert a pressure of 200 pounds on each square inch of the interior of the boiler.

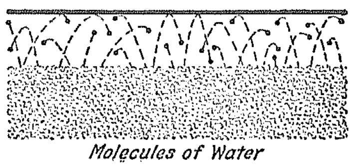


Fig. 10

**33.** For every pressure, there is a definite temperature at which water will boil. This is to be expected because, as the pressure on the water increases, the temperature, or the rate of vibration of the molecules of the water, must be increased before other molecules can be expelled. The relation between

temperature and pressure as well as other data relating to steam is found in the steam tables.

Under atmospheric pressure, or 14.7 pounds per square inch, water will boil or change into steam when its temperature reaches 212° F. At 200 pounds gauge pressure, the boiling temperature of water is about 388° F.

34. **Saturated Steam.**—Saturated steam is steam that is in direct contact with the water from which it was formed, and it has the same temperature as the water. Thus, the steam in a locomotive boiler is saturated steam, but this does not mean that it is necessarily wet steam. If the water in a boiler is dirty, or if the boiling is very violent, particles of water may be cast up into the steam and be held in it as a sort of mist or spray. Such steam is called wet saturated steam. But if the steam is free from all trace of moisture, or, in other words, if it is completely vaporized, it is called dry saturated steam. The term saturated has no reference whatever to moisture; it refers to heat. Steam is saturated when it has taken up all the heat necessary to maintain it as a dry vapor. It is in such a condition that the slightest loss of heat will cause a part of the steam to condense.

35. **Superheated Steam.**—So long as the steam in a boiler is in close communication with the water, the steam cannot be otherwise than saturated. Any attempt to heat the steam to a higher temperature will merely cause more water to be evaporated. To increase the temperature of the steam, it must be removed from the presence of water, and more heat added to it. Steam that has been heated after it has been removed from contact with water is called superheated steam. A device used to superheat steam is called a superheater.

36. **Degree of Superheat.**—The difference between the temperature of superheated steam and saturated steam with both at the same pressure, is known as the degree of superheat. Thus, at 200 pounds gauge pressure, the temperature of saturated steam is 388° F. and, at the same pressure when superheated, the temperature of the steam may be 588° F. The degree of superheat is the difference between 588° and 388° F., or 200° F.

**37. Temperature and Pressure.**—Owing to the additional heat that has been imparted to superheated steam, its molecules vibrate much more rapidly than the molecules of saturated

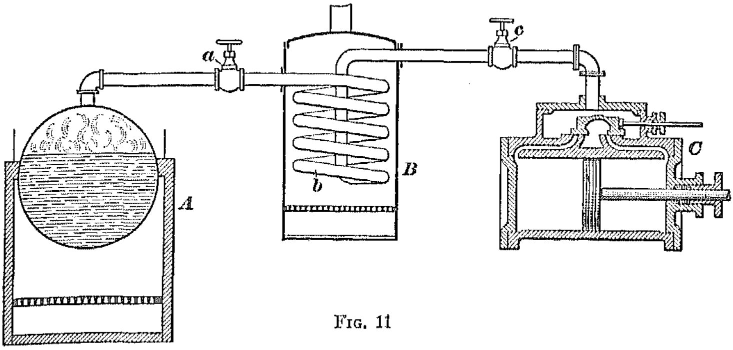



FIG. 11

steam. As the pressure of the steam is dependent on the rate of vibration of its molecules, it would be natural to assume that steam when superheated would be at a higher pressure than when in the saturated state. This may or may not be the case and will depend on the manner in which the superheating is done.

In Fig. 11, if the steam from the boiler *A* is permitted to enter the coil *b*, and if the cocks *a* and *c* are then closed, the heat in the drum *B* will increase the rate of vibration of the molecules, hence the pressure exerted by them will increase. However, if steam is permitted to enter the bottom of a chamber *a*, Fig. 12, and if, as the steam is heated, the piston *b* is raised up a little at a time so as to allow the molecules of steam to occupy more space as their vibrations are increased by being heated, the result will be different. If the piston is raised at the proper rate, the pressure will remain constant, because, although the molecules are vibrating faster, they are now free to move farther apart, thereby losing velocity, and as a result they strike no harder against the walls of the chamber.

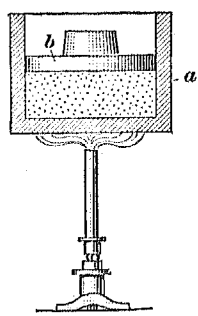



FIG. 12

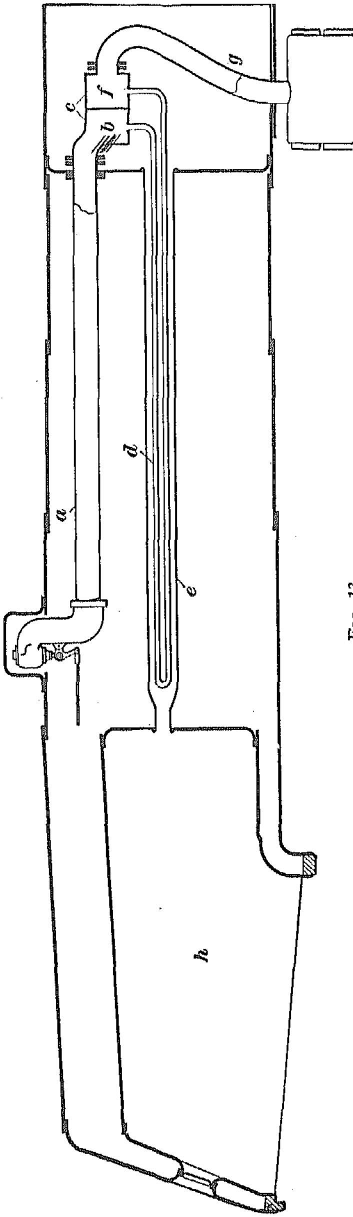


FIG. 13

Therefore, it is possible to superheat steam and increase the vibrations of its molecules without increasing the pressure, provided the molecules are permitted to move farther apart as their vibrations increase.

**38. Method of Superheating.**—The method used to superheat steam in a locomotive is illustrated in the conventional arrangement shown in Fig. 13. The steam passes from the boiler, through the dry pipe *a* to the compartment *b* in the superheater header *c*. Next the steam passes through the superheater units *d*, one shown, within the large flue *e*, to the compartment *f* in the superheater header. From the compartment *f*, the steam passes to the steam chests through the steam pipes *g*, one shown. The hot gases that are passing from the firebox *h* to the smokebox through the flue *e*, impart heat to the steam in the superheater unit and the molecules of steam receive additional vibration. With an actual superheater header, there are a large number of compartments *b* and *f* and hence a large number of units *d*.

The pressure of the steam in the superheater unit *d* does not increase, even though the molecules of steam are vibrating more rapidly than in the boiler. The reason is that the almost constant passage of steam to the steam chest with the locomotive in operation, is taking the steam away from the unit, and this gives the same effect on the steam in the coil as if it were being enlarged enough to prevent the increased vibration of the steam molecules from causing an increase in pressure. In other words, the molecules in the coil are free to move farther apart in the direction of the steam chest, hence increased vibration of the molecules does not result in increased pressure. Therefore, the condition under which superheating is taking place is similar to that in Fig. 12.

**39. Difference Between Saturated and Superheated Steam.** The important difference between saturated and superheated steam is that, with saturated steam, the force with which the steam molecules are expelled from the liquid exceeds only slightly the force of attraction between the molecules. A slight decrease in the velocity of the steam molecules causes the force of attraction to pull and hold them together and thereby form water, or the steam condenses. The loss of steam through the condensation of saturated steam runs as high as 30 per cent.

On the other hand, the molecules of superheated steam are in more rapid motion and the force of attraction between the molecules will not act to bring them together and form water until their rate of movement is slightly less than that of saturated steam at the same pressure. Therefore, the increased rate of vibration of the molecules of superheated steam delays condensation.

**40. Advantages of Superheating Steam.**—Briefly, the advantage of superheating steam is that the same effect is obtained as if the capacity of the boiler for generating steam was increased. This is explained as follows: The steam that was formerly lost by condensation is now saved, and this is equivalent to a corresponding increase in the capacity of the boiler to generate steam. A greater steam-generating capacity means that a higher cylinder pressure with an accompanying

greater drawbar pull can be maintained at higher speeds. In other words, the engine steams more freely than otherwise and the steam is generated fast enough to maintain the pressure in the cylinders nearer to the working pressure at higher speeds.

**41. High-Temperature Steam.**—As heat can be converted into work, it follows that, as the temperature of the steam is increased, more heat becomes available for the performance of work. However, any increase in the temperature of the steam above that ordinarily used in locomotive service is obtained only at the expense of an abnormal increase in pressure. For example, to obtain an increase of 18° F. with the pressure already at 200 pounds will result in an increase in pressure of 50 pounds, and to obtain an increase in temperature of 19° F. with the pressure at 250 pounds requires an increase in pressure to 310 pounds. Thus, the increase in pressure is not proportional; the pressure increases more rapidly than the temperature.

With the boiler pressure somewhat in excess of 250 pounds, the water-tube firebox must be resorted to because the ordinary box type of firebox cannot be stayed to withstand high pressures. The principal objection to the water-tube firebox, unless the feed-water is pure, is the difficulty experienced and the time consumed in keeping the water tubes free from scale.

**42. *Utilization of High-Temperature Steam.***—The amount of work obtained from heat in a locomotive depends on the difference between the temperature of the steam at admission to the cylinder and its temperature at exhaust. Therefore, the efficient use of high-temperature steam or of high-pressure steam, if this latter phrase is preferred, is a matter of using the steam expansively and thereby obtaining a low exhaust-steam temperature. The required expansion cannot be obtained with the conventional locomotive, as it is of the single-expansion type, and some system whereby the steam would be expanded twice, such as compounding, would have to be resorted to, in order to use the steam economically. Therefore, while theoretically the use of high-temperature steam is advantageous, yet its application to locomotive practice offers difficulties due to the radical changes required in the design of the boiler and engine.

With boiler pressures around 250 pounds per square inch, a certain degree of expansion can be secured by an increase in the steam lap. However, a wide steam lap requires a long valve travel if a late maximum cut-off is to be obtained; the travel that can be secured with the ordinary valve gear is limited.

A wide steam lap can be obtained by sacrificing a late maximum cut-off. Thus, a considerable number of locomotives have been constructed with the maximum cut-off limited to 50 or 60 per cent., starting ports being employed to supplement the steam ports when lifting trains. The wide steam lap insures adequate expansion of the steam. The term limited cut-off is applied to this type of locomotive.

43. **Increasing the Drawbar Horsepower.**—Any device that causes the heat of the burning fuel in the firebox to be utilized more fully in the generation of steam serves to increase the capacity of the boiler to generate steam and thereby increases the drawbar horsepower. Such devices include the superheater, arch tubes, thermic siphons, brick arches, combustion chambers, feed-water heaters, and exhaust-steam injectors. All these devices serve to increase the capacity of the boiler to make steam without any increase in the quantity of fuel burned.

The superheater uses the heat of the gases from the firebox to heat the steam on its passage to the cylinders, thus saving steam by preventing condensation. Any saving in steam is equivalent to an increase in the capacity of the boiler to make steam, by the amount saved.

44. Arch tubes and thermic siphons speed up the circulation of the water in the boiler, thereby permitting the water to absorb the heat more rapidly and thus increase the rate at which steam is being generated.

The brick arch is a mixing device that serves to mix the gases of combustion with the oxygen of the air. An excess of oxygen above the fuel bed does not imply a complete combustion of the gases; they must be intimately mixed with the oxygen and given time to burn.

The combustion chamber provides a space for the combustion of the gases, sparks, and cinders that may leave the firebox

unburned. Therefore, the brick arch and the combustion chamber cause the heat of the burning fuel to be more fully utilized in the generation of steam.

The feed-water heater reclaims heat that otherwise would be wasted by using the heat of the gases from the firebox to heat the feed-water before it enters the boiler. This action increases the rate at which the steam is generated because the feed-water, being already heated, can be more quickly turned into steam.

**45.** The exhaust-steam injector is operated by exhaust steam; hence, the steam ordinarily taken from the boiler to operate the injector is saved, and this is the same as if the capacity of the boiler to generate steam were increased by the amount of steam saved.

Sometimes the size of the firebox is increased so as to keep the rate of combustion within more reasonable limits, thereby giving a higher firebox temperature and an increase in the steam-generating capacity. Fireboxes of this size are usually carried on four-wheel trailing trucks.

It should be remembered that all devices that serve to increase the steam-generating capacity of the boiler also serve to keep the size of the boiler within reasonable limits. A locomotive boiler that would generate steam at the same rate as a modern boiler equipped with the devices just mentioned would have to be made of such a size as to be impracticable.

## STEAM TABLES

### PROPERTIES OF SATURATED STEAM

**46.** Saturated steam possesses a number of properties that change as the pressure on the steam is changed. These properties are as follows: (1) the temperature of the steam; (2) the heat of the liquid; (3) the latent heat of vaporization, usually called latent heat; (4) the total heat of vaporization, or the total heat; (5) the volume of the steam; (6) the weight of the steam.

The foregoing properties have been determined by experiment and arranged in tables called Steam Tables. See Table I. The quantities given in the steam table are for one pound of water

or steam; therefore, to find the heat of the liquid, the latent heat, or the total heat of a greater weight of water or steam, it is necessary to multiply the quantity given in the steam table by the weight of the water or the steam that is being considered.

## EXPLANATION OF SATURATED-STEAM TABLE

47. **Pressure.**—All of the properties of saturated steam depend on the absolute pressure under which it is formed; hence, in the steam table, pressure is the first item given. The pressure offers a resistance to the expulsion of the steam particles from the water and the amount of this resistance determines the other properties of the steam.

For example, if water boils under atmospheric pressure, or 14.7 pounds per square inch, the temperature of the water and the steam is 212° F., the heat of the liquid, if one pound is considered, is 180 B. t. u., the latent heat is 971.7 B. t. u., and the total heat is 1151.7 B. t. u.

On the other hand, if the pressure is 50 pounds absolute, the temperature of the water and the steam will be 281° F., the heat of the liquid will be 249.8 heat units, the latent heat 925.9 heat units, and the total heat 1175.6 heat units.

It will be noted that absolute pressures are used in the steam table; that is, the pressure is reckoned from the point of vacuum, or no pressure. Absolute pressure is the weight of the atmosphere, or 14.7 pounds per square inch, greater than gauge pressure; that is, when the gauge registers no pressure, the corresponding absolute pressure is 14.7 pounds. Therefore, 14.7 pounds must be added to a gauge pressure before it can be used with this table.

48. **Temperature of Evaporation.**—The second column of the steam table gives the temperatures at which water will boil when under the absolute pressures given in the first column. The temperature of the steam generated will be the same as the temperature of the water. The steam table shows that the boiling temperature increases as the pressure increases, and decreases as the pressure decreases. At atmospheric pressure, or 14.7 pounds per square inch, the boiling temperature is 212° F.; at

## TABLE I

### PROPERTIES OF SATURATED STEAM

(Compiled from Prof. G. A. Goodenough's Steam Table and printed with his permission and that of the publisher, John Wiley & Sons, Inc.)

| Absolute Pressure Pounds per Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 1 | 101.76 | 69.76 | 1035.6 | 1105.4 | 333.3 | .00300 |
| 2 | 126.10 | 94.02 | 1022.2 | 1116.2 | 173.6 | .00576 |
| 3 | 141.49 | 109.38 | 1013.5 | 1122.9 | 118.7 | .00843 |
| 4 | 152.99 | 120.9 | 1007.0 | 1127.9 | 90.6 | .01104 |
| 5 | 162.25 | 130.1 | 1001.6 | 1131.7 | 73.5 | .01360 |
| 6 | 170.07 | 137.9 | 997.1 | 1135.0 | 62.0 | .01614 |
| 7 | 176.85 | 144.7 | 993.1 | 1137.8 | 53.7 | .01864 |
| 8 | 182.87 | 150.8 | 989.5 | 1140.3 | 47.35 | .02112 |
| 9 | 188.28 | 156.2 | 986.3 | 1142.5 | 42.41 | .02358 |
| 10 | 193.21 | 161.1 | 983.3 | 1144.4 | 38.43 | .02602 |
| 11 | 197.75 | 165.7 | 980.5 | 1146.2 | 35.16 | .02844 |
| 12 | 201.96 | 169.9 | 978.0 | 1147.9 | 32.41 | .03086 |
| 13 | 205.88 | 173.8 | 975.6 | 1149.4 | 30.07 | .03326 |
| 14 | 209.56 | 177.5 | 973.3 | 1150.8 | 28.06 | .03564 |
| 14.7 | 212 | 180.0 | 971.7 | 1151.7 | 26.81 | .03730 |
| 15 | 213.0 | 181.0 | 971.2 | 1152.2 | 26.30 | .03802 |
| 16 | 216.3 | 184.3 | 969.1 | 1153.4 | 24.76 | .04038 |
| 18 | 222.4 | 190.5 | 965.2 | 1155.7 | 22.18 | .04508 |
| 20 | 228.0 | 196.0 | 961.7 | 1157.7 | 20.10 | .0498 |
| 22 | 233.1 | 201.2 | 958.4 | 1159.6 | 18.38 | .0544 |
| 24 | 237.8 | 206.0 | 955.3 | 1161.3 | 16.95 | .0590 |
| 26 | 242.2 | 210.4 | 952.4 | 1162.8 | 15.73 | .0636 |
| 28 | 246.4 | 214.6 | 949.7 | 1164.3 | 14.67 | .0681 |
| 30 | 250.3 | 218.6 | 947.1 | 1165.7 | 13.76 | .0727 |
| 32 | 254.0 | 222.4 | 944.6 | 1166.9 | 12.95 | .0772 |
| 34 | 257.6 | 225.9 | 942.2 | 1168.1 | 12.24 | .0818 |
| 36 | 260.9 | 229.4 | 939.9 | 1169.2 | 11.60 | .0862 |
| 38 | 264.2 | 232.6 | 937.7 | 1170.3 | 11.03 | .0907 |
| 40 | 267.2 | 235.8 | 935.5 | 1171.3 | 10.51 | .0951 |
| 42 | 270.2 | 238.8 | 933.5 | 1172.2 | 10.04 | .0996 |
| 44 | 273.0 | 241.7 | 931.5 | 1173.2 | 9.61 | .1040 |
| 46 | 275.8 | 244.5 | 929.6 | 1174.0 | 9.22 | .1085 |
| 48 | 278.4 | 247.2 | 927.7 | 1174.8 | 8.86 | .1129 |
| 50 | 281.0 | 249.8 | 925.9 | 1175.6 | 8.53 | .1173 |

**TABLE I—Continued**

| Absolute Pressure Pounds per Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 52 | 283.5 | 252.3 | 924.1 | 1176.4 | 8.22 | .1217 |
| 54 | 285.9 | 254.7 | 922.4 | 1177.1 | 7.93 | .1261 |
| 56 | 288.2 | 257.1 | 920.7 | 1177.8 | 7.67 | .1304 |
| 58 | 290.5 | 259.5 | 919.0 | 1178.5 | 7.42 | .1348 |
| 60 | 292.7 | 261.7 | 917.4 | 1179.1 | 7.18 | .1392 |
| 62 | 294.9 | 263.9 | 915.8 | 1179.7 | 6.97 | .1435 |
| 64 | 296.9 | 266.1 | 914.3 | 1180.3 | 6.76 | .1479 |
| 66 | 299.0 | 268.2 | 912.7 | 1180.9 | 6.57 | .1522 |
| 68 | 301.0 | 270.2 | 911.2 | 1181.5 | 6.39 | .1566 |
| 70 | 302.9 | 272.2 | 909.8 | 1182.0 | 6.22 | .1609 |
| 72 | 304.8 | 274.2 | 908.3 | 1182.5 | 6.05 | .1652 |
| 74 | 306.7 | 276.1 | 906.9 | 1183.0 | 5.90 | .1695 |
| 76 | 308.5 | 278.0 | 905.5 | 1183.5 | 5.75 | .1738 |
| 78 | 310.3 | 279.8 | 904.2 | 1184.0 | 5.61 | .1781 |
| 80 | 312.0 | 281.6 | 902.8 | 1184.4 | 5.48 | .1824 |
| 82 | 313.7 | 283.4 | 901.5 | 1184.9 | 5.35 | .1868 |
| 84 | 315.4 | 285.1 | 900.2 | 1185.3 | 5.23 | .1910 |
| 86 | 317.1 | 286.8 | 898.9 | 1185.7 | 5.12 | .1953 |
| 88 | 318.7 | 288.5 | 897.7 | 1186.1 | 5.01 | .1996 |
| 90 | 320.3 | 290.1 | 896.4 | 1186.5 | 4.905 | .2039 |
| 92 | 321.8 | 291.7 | 895.2 | 1186.9 | 4.805 | .2081 |
| 94 | 323.3 | 293.3 | 894.0 | 1187.3 | 4.709 | .2124 |
| 96 | 324.8 | 294.8 | 892.8 | 1187.7 | 4.617 | .2166 |
| 98 | 326.3 | 296.4 | 891.6 | 1188.0 | 4.528 | .2209 |
| 100 | 327.8 | 297.9 | 890.5 | 1188.4 | 4.442 | .2251 |
| 102 | 329.2 | 299.4 | 889.3 | 1188.7 | 4.359 | .2294 |
| 104 | 330.7 | 300.9 | 888.2 | 1189.0 | 4.279 | .2337 |
| 106 | 332.0 | 302.3 | 887.1 | 1189.4 | 4.202 | .2380 |
| 108 | 333.4 | 303.7 | 885.9 | 1189.7 | 4.128 | .2422 |
| 110 | 334.8 | 305.1 | 884.8 | 1190.0 | 4.057 | .2465 |
| 112 | 336.1 | 306.5 | 883.7 | 1190.3 | 3.988 | .2508 |
| 114 | 337.4 | 307.9 | 882.7 | 1190.6 | 3.921 | .2550 |
| 116 | 338.7 | 309.2 | 881.6 | 1190.8 | 3.857 | .2593 |
| 118 | 340.0 | 310.6 | 880.6 | 1191.1 | 3.795 | .2635 |
| 120 | 341.3 | 311.9 | 879.5 | 1191.4 | 3.735 | .2678 |
| 122 | 342.5 | 313.2 | 878.5 | 1191.6 | 3.676 | .2720 |
| 124 | 343.7 | 314.4 | 877.5 | 1191.9 | 3.620 | .2762 |
| 126 | 345.0 | 315.7 | 876.4 | 1192.1 | 3.566 | .2805 |

TABLE I—Continued

| Absolute Pressure Poundsper Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 128 | 346.2 | 316.9 | 875.4 | 1192.4 | 3.513 | .2847 |
| 130 | 347.4 | 318.2 | 874.4 | 1192.6 | 3.461 | .2889 |
| 132 | 348.5 | 319.4 | 873.5 | 1192.9 | 3.412 | .2931 |
| 134 | 349.7 | 320.6 | 872.5 | 1193.1 | 3.363 | .2973 |
| 136 | 350.8 | 321.8 | 871.5 | 1193.3 | 3.316 | .3016 |
| 138 | 352.0 | 323.0 | 870.5 | 1193.5 | 3.270 | .3058 |
| 140 | 353.1 | 324.2 | 869.6 | 1193.7 | 3.226 | .3100 |
| 142 | 354.2 | 325.3 | 868.6 | 1193.9 | 3.182 | .3142 |
| 144 | 355.3 | 326.5 | 867.7 | 1194.1 | 3,140 | .3184 |
| 146 | 356.3 | 327.6 | 866.8 | 1194.3 | 3.099 | .3227 |
| 148 | 357.4 | 328.7 | 865.8 | 1194.5 | 3.059 | .3269 |
| 150 | 358.5 | 329.8 | 864.9 | 1194.7 | 3.020 | .3311 |
| 155 | 361.1 | 332.5 | 862.7 | 1195.2 | 2.927 | .3417 |
| 160 | 363.6 | 335.2 | 860.5 | 1195.7 | 2.839 | .3522 |
| 165 | 366.1 | 337.8 | 858.3 | 1196.1 | 2.757 | .3627 |
| 170 | 368.5 | 340.3 | 856.2 | 1196.5 | 2.679 | .3733 |
| 175 | 370.8 | 342.8 | 854.1 | 1196.9 | 2.605 | .3838 |
| 180 | 373.1 | 345.2 | 852.0 | 1197.2 | 2.536 | .3943 |
| 185 | 375.4 | 347.6 | 849.9 | 1197.6 | 2,470 | .4048 |
| 190 | 377.6 | 350.0 | 847.9 | 1197.9 | 2.408 | .4154 |
| 195 | 379.7 | 352.2 | 846.0 | 1198.2 | 2.348 | .4259 |
| 200 | 381.9 | 354.5 | 844.0 | 1198.5 | 2.292 | .4364 |
| 205 | 383.9 | 356.7 | 842.1 | 1198.7 | 2.238 | .4469 |
| 210 | 386.0 | 358.8 | 840.2 | 1199.0 | 2.186 | .457 |
| 215 | 388.0 | 361.0 | 838.3 | 1199.2 | 2.137 | .468 |
| 220 | 390.0 | 363.0 | 836.5 | 1199.5 | 2.090 | .478 |
| 225 | 391.9 | 365.1 | 834.6 | 1199.7 | 2.045 | .489 |
| 230 | 393.8 | 367.1 | 832.8 | 1199.9 | 2.002 | .499 |
| 235 | 395.6 | 369.1 | 831.0 | 1200.1 | 1.961 | .510 |
| 240 | 397.5 | 371.0 | 829.3 | 1200.3 | 1.921 | .521 |
| 245 | 399.3 | 373.0 | 827.5 | 1200.5 | 1.883 | .531 |
| 250 | 401.1 | 374.9 | 825.8 | 1200.6 | 1.846 | .542 |
| 255 | 402.9 | 376.7 | 824.1 | 1200.8 | 1.811 | .552 |
| 260 | 404.5 | 378.6 | 822.4 | 1201.0 | 1.777 | .563 |
| 265 | 406.2 | 380.4 | 820.7 | 1201.1 | 1.745 | .573 |
| 270 | 407.9 | 382.2 | 819.1 | 1201.2 | 1.713 | .584 |
| 275 | 409.6 | 383.9 | 817.4 | 1201.4 | 1.683 | .594 |
| 280 | 411.2 | 385.7 | 815.8 | 1201.5 | 1.654 | .605 |

TABLE I—Continued

| Absolute Pressure Pounds per Sq. In. $p$ | Temperature Degrees F. $t$ | Heat of the Liquid B. t. u. $q$ | Latent Heat of Vaporization B. t. u. $l$ | Total Heat B. t. u. $h$ | Volume per Pound Cubic Feet $v$ | Weight per Cubic Foot Pounds $w$ |
|---|---|---|---|---|---|---|
| 285 | 412.8 | 387.4 | 814.2 | 1201.6 | 1.625 | .615 |
| 290 | 414.4 | 389.1 | 812.6 | 1201.7 | 1.598 | .626 |
| 295 | 415.9 | 390.8 | 811.0 | 1201.8 | 1.571 | .636 |
| 300 | 417.5 | 392.4 | 809.4 | 1201.9 | 1.545 | .647 |
| 310 | 420.5 | 395.7 | 806.4 | 1202.0 | 1.496 | .668 |
| 320 | 423.4 | 398.9 | 803.3 | 1202.2 | 1.450 | .690 |
| 330 | 426.3 | 402.0 | 800.3 | 1202.3 | 1.407 | .711 |
| 340 | 429.1 | 405.0 | 797.4 | 1202.4 | 1.366 | .732 |
| 350 | 431.9 | 408.0 | 794.5 | 1202.5 | 1.327 | .753 |
| 360 | 434.6 | 410.9 | 791.6 | 1202.5 | 1.291 | .775 |
| 370 | 437.2 | 413.7 | 788.8 | 1202.6 | 1.256 | .796 |
| 380 | 439.8 | 416.5 | 786.1 | 1202.6 | 1.223 | .817 |
| 390 | 442.3 | 419.3 | 783.3 | 1202.6 | 1.192 | .839 |
| 400 | 444.8 | 422.0 | 780.6 | 1202.5 | 1.162 | .860 |
| 410 | 447.2 | 424.6 | 777.9 | 1202.5 | 1.134 | .882 |
| 420 | 449.6 | 427.2 | 775.2 | 1202.4 | 1.107 | .903 |
| 430 | 451.9 | 429.8 | 772.6 | 1202.4 | 1.081 | .925 |
| 440 | 454.2 | 432.3 | 770.0 | 1202.3 | 1.056 | .947 |
| 450 | 456.5 | 434.8 | 767.4 | 1202.2 | 1.033 | .968 |
| 460 | 458.7 | 437.2 | 764.9 | 1202.1 | 1.010 | .990 |
| 470 | 460.9 | 439.6 | 762.4 | 1202.0 | .988 | 1.012 |
| 480 | 463.1 | 442.0 | 759.9 | 1201.9 | .968 | 1.033 |
| 490 | 465.2 | 444.3 | 757.5 | 1201.8 | .948 | 1.055 |
| 500 | 467.2 | 446.6 | 755.0 | 1201.7 | .928 | 1.077 |

5 pounds, absolute, the temperature is 162.25; whereas, at 100 pounds, absolute, or a gauge pressure of 85 pounds, the boiling temperature is 327.8° F. The foregoing is explained by the fact that, as the pressure on the water is increased, a higher temperature, or a greater vibration of the water molecules, is required before the molecules can overcome the pressure and be expelled as steam. The reverse will hold true as the pressure is decreased. Therefore, there is a different boiling temperature for each pressure.

**49. Heat of the Liquid.**—The heat of the liquid is the quantity of heat as measured in heat units that must be added

to water to raise its temperature from 32° F., or the freezing point, to the boiling temperature. It has already been explained that the boiling temperature varies with the pressure, hence there will be a different heat of the liquid for each different pressure. The heat of the liquid per pound of water is given for various pressures in the third column of the steam table.

One B. t. u. raises the temperature of 1 pound of water one degree, two B. t. u. raises the temperatures two degrees, and so on; hence the heat of the liquid will be equal, approximately, to the boiling temperature less 32°. Thus, the values in the third column of the steam table may be obtained approximately by subtracting 32 from the corresponding temperature in the second column. This method of calculating the heat of the liquid does not give exact results, because at some temperatures one B. t. u. will raise one pound of water more than one degree and at other temperatures less than one degree.

*It must not be assumed that water at a temperature less than* 32° F. contains no heat; actually, any substance above absolute zero contains some heat. The freezing point of water, or 32° F., is merely taken as a starting point in calculating the heat of the liquid. Therefore, the heat of the liquid as shown by the steam table is not all of the heat that the steam really contains, but merely the amount that has been added to a pound of water above 32° F.

**50. Latent Heat of Steam.**—The latent heat is the heat that must be added to water to convert it into steam after the boiling point has been reached.

After the water begins to boil, a large amount of heat must be applied to it to convert it completely into steam. A thermometer placed in the water after the boiling temperature is reached will show no increase in temperature; hence the heat that is being used in converting the water into steam is called latent heat. A great deal more heat is required to convert a pound of water into steam than is required to raise it to the boiling point. For example, at atmospheric pressure, as shown in the third column of the steam table, 180 B. t. u. is necessary to raise the temperature of one pound of water to the boiling

point, whereas the fourth column shows that 971.7 B. t. u. is required to convert the pound of water completely into steam. The heat of the liquid is used to increase the temperature of the water, whereas the latent heat is used to break down the attraction of the molecules of water for each other and expel them as steam against the pressure existing on the surface of the water. The heat of the liquid increases with the pressure, the latent heat decreases with the pressure.

**51. Total Heat of Steam.**—The total heat of steam in B. t. u. is given in the fifth column of the steam table and is *defined* as all of the heat required to heat one pound of water from 32° F. to the boiling temperature and then change it into steam. The total heat of the steam is, then, the sum of the heat of the liquid and the latent heat, or it is the sum of columns three and four of the steam table.

The increase in the total heat of steam is small as the pressure increases; this is due to the fact that, although the heat of the liquid increases with the pressure, the latent heat decreases.

Although the gain in the total heat of one pound of steam in B. t. u. is small as the pressure is increased, yet the slight increase represents a considerable amount of work when the steam consumption of a locomotive is considered. The difference between the total heat of one pound of steam, Table II, at 250 pounds gauge pressure, superheated 200°, and a pound at 200 pounds pressure is $1315.6-1309.7$ or 5.9 B. t. u. Now the steam consumption of a locomotive per hour is about equal to the horsepower multiplied by 17.5, hence a locomotive of 2500 horsepower uses $2500\times17.5$ or 43,750 pounds of steam. An increase of 5.9 B. t. u. in the total heat of each pound of this steam represents a gain of $43750\times5.9$, or 258,125 B. t. u. available for the performance of work with the higher pressure.

**52. Volume Per Pound.**—The sixth column of the steam table gives the volume a pound of steam occupies for the different pressures. Thus, a pound of steam under 215 pounds absolute pressure, or about 200 pounds gauge pressure, occupies 2.137 cubic feet. The volume of the steam, of course, decreases with the pressure.

## TABLE II

### PROPERTIES OF SATURATED AND SUPERHEATED STEAM

| Absolute Pressure Pounds per Sq. In. | Saturated Steam | | Degrees of Superheat | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 200 | | 250 | | 300 | |
| | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. | Temperature Degrees F. | Total Heat B. t. u. |
| 200 | 381.9 | 1198.5 | 581.9 | 1307.7 | 631.9 | 1332.4 | 681.9 | 1357.0 |
| 205 | 383.9 | 1198.7 | 583.9 | 1308.3 | 633.9 | 1333.0 | 683.9 | 1357.7 |
| 210 | 386.0 | 1199.0 | 586.0 | 1309.0 | 636.0 | 1333.7 | 686.0 | 1358.4 |
| 215 | 388.0 | 1199.2 | 588.0 | 1309.7 | 638.0 | 1334.4 | 688.0 | 1359.1 |
| 220 | 390.0 | 1199.5 | 590.0 | 1310.3 | 640.0 | 1335.1 | 690.0 | 1359.8 |
| 225 | 391.9 | 1199.7 | 591.9 | 1310.9 | 641.9 | 1335.7 | 691.9 | 1360.3 |
| 230 | 393.8 | 1199.9 | 593.8 | 1311.6 | 643.8 | 1336.3 | 693.8 | 1361.0 |
| 235 | 395.6 | 1200.1 | 595.6 | 1312.2 | 645.6 | 1337.0 | 695.6 | 1361.7 |
| 240 | 397.5 | 1200.3 | 597.5 | 1312.8 | 647.5 | 1337.6 | 697.5 | 1362.3 |
| 245 | 399.3 | 1200.5 | 599.3 | 1313.3 | 649.3 | 1338.2 | 699.3 | 1362.9 |
| 250 | 401.1 | 1200.6 | 601.1 | 1313.9 | 651.1 | 1338.8 | 701.1 | 1363.5 |
| 255 | 402.9 | 1200.8 | 602.9 | 1314.5 | 652.9 | 1339.3 | 702.9 | 1364.1 |
| 260 | 404.5 | 1201.0 | 604.5 | 1315.1 | 654.5 | 1340.0 | 704.5 | 1364.7 |
| 265 | 406.2 | 1201.1 | 606.2 | 1315.6 | 656.2 | 1340.5 | 706.2 | 1365.3 |
| 270 | 407.9 | 1201.2 | 607.9 | 1316.2 | 657.9 | 1341.1 | 707.9 | 1365.9 |
| 275 | 409.6 | 1201.4 | 609.6 | 1316.7 | 659.6 | 1341.6 | 709.6 | 1366.5 |
| 280 | 411.2 | 1201.5 | 611.2 | 1317.2 | 661.2 | 1342.2 | 711.2 | 1367.0 |
| 285 | 412.8 | 1201.6 | 612.8 | 1317.8 | 662.8 | 1342.7 | 712.8 | 1367.5 |
| 290 | 414.4 | 1201.7 | 614.4 | 1318.3 | 664.4 | 1343.2 | 714.4 | 1368.0 |
| 295 | 415.9 | 1201.8 | 615.9 | 1318.8 | 665.9 | 1343.8 | 715.9 | 1368.7 |
| 300 | 417.5 | 1201.9 | 617.5 | 1319.3 | 667.5 | 1344.3 | 717.5 | 1369.2 |
| 305 | 419.0 | 1204.3 | 619.0 | 1319.8 | 669.0 | 1344.8 | 719.0 | 1369.7 |
| 310 | 420.5 | 1202.0 | 620.5 | 1320.3 | 670.5 | 1345.3 | 720.5 | 1370.2 |
| 320 | 423.4 | 1202.2 | 623.4 | 1321.3 | 673.4 | 1346.3 | 723.4 | 1371.3 |
| 330 | 426.3 | 1202.3 | 626.3 | 1322.2 | 676.3 | 1347.3 | 726.3 | 1372.3 |
| 340 | 429.1 | 1202.4 | 629.1 | 1323.2 | 679.1 | 1348.3 | 729.1 | 1373.3 |
| 350 | 431.9 | 1202.5 | 631.9 | 1324.1 | 681.9 | 1349.3 | 731.9 | 1374.3 |
| 360 | 434.6 | 1202.5 | 634.6 | 1325.0 | 684.6 | 1350.2 | 734.6 | 1375.3 |
| 370 | 437.2 | 1202.6 | 637.2 | 1325.9 | 687.2 | 1351.1 | 737.2 | 1365.9 |
| 380 | 439.8 | 1202.6 | 639.8 | 1326.8 | 689.8 | 1352.0 | 739.8 | 1377.1 |
| 390 | 442.3 | 1202.6 | 642.3 | 1327.7 | 692.3 | 1353.0 | 742.3 | 1378.1 |
| 400 | 444.8 | 1202.5 | 644.8 | 1328.6 | 694.8 | 1353.9 | 744.8 | 1379.1 |
| 425 | 450.8 | 1208.0 | 650.8 | 1331.0 | 700.8 | 1356.0 | 750.8 | 1381.0 |
| 450 | 456.5 | 1202.2 | 656.5 | 1333.0 | 706.5 | 1358.0 | 756.5 | 1383.0 |
| 475 | 462.1 | 1209.0 | 662.1 | 1335.0 | 712.1 | 1360.0 | 762.1 | 1385.0 |
| 500 | 467.2 | 1201.7 | 667.2 | 1337.0 | 717.2 | 1362.0 | 767.2 | 1388.0 |

**53. Weight per Cubic Foot.**—The seventh column of the steam table gives the weight of a cubic foot of steam under the different pressures. The weight increases with the pressure because a greater number of particles of steam will be contained in a cubic foot when the pressure is high than when low.

### SUPERHEATED STEAM TABLE

**54.** The second and third columns of Table II refer to saturated steam and are taken from Table I; the other columns of the table relate to steam that has been superheated to 200° F., 250° F., and 300° F.

The following example will explain how the table is to be used. At an absolute pressure of 200 pounds, water boils at a temperature of 381.9° F. and the total heat of one pound of water is 1198.5 B. t. u. If the steam is superheated 200° F. the temperature becomes 381.9 plus 200, or 581.9° F.; the total heat of the steam is now 1307.7, or an increase of 1307.7 minus 1198.5, or 109.2 B. t. u. The total heat of the steam when superheated 250° F. and 300° F. is 1332.4 and 1357.0 B. t. u.; thus, the total heat increases with the superheat.

## LOCOMOTIVE SUPERHEATERS

### ELESCO TYPE A SUPERHEATER

**55. General Arrangement.**—The purpose of the locomotive superheater is to utilize the heat of the gases from the firebox to impart additional heat to the steam on its passage to the steam chests. As shown in Fig. 14, the Elesco type A superheater consists of a header *a* to which the dry pipe *b* and the steam pipes *c* are connected; the superheater units *d* that are connected to the header and extend back into the superheater flues *e*; and a damper *f* that is actuated by the damper mechanism *g*.

**56. Superheater Header.**—An exterior view of a through-bolt superheater header, turned bottom side up, is shown in Fig. 15. Its purpose is to distribute the steam from the dry pipe to the superheater units, and from the units to the steam

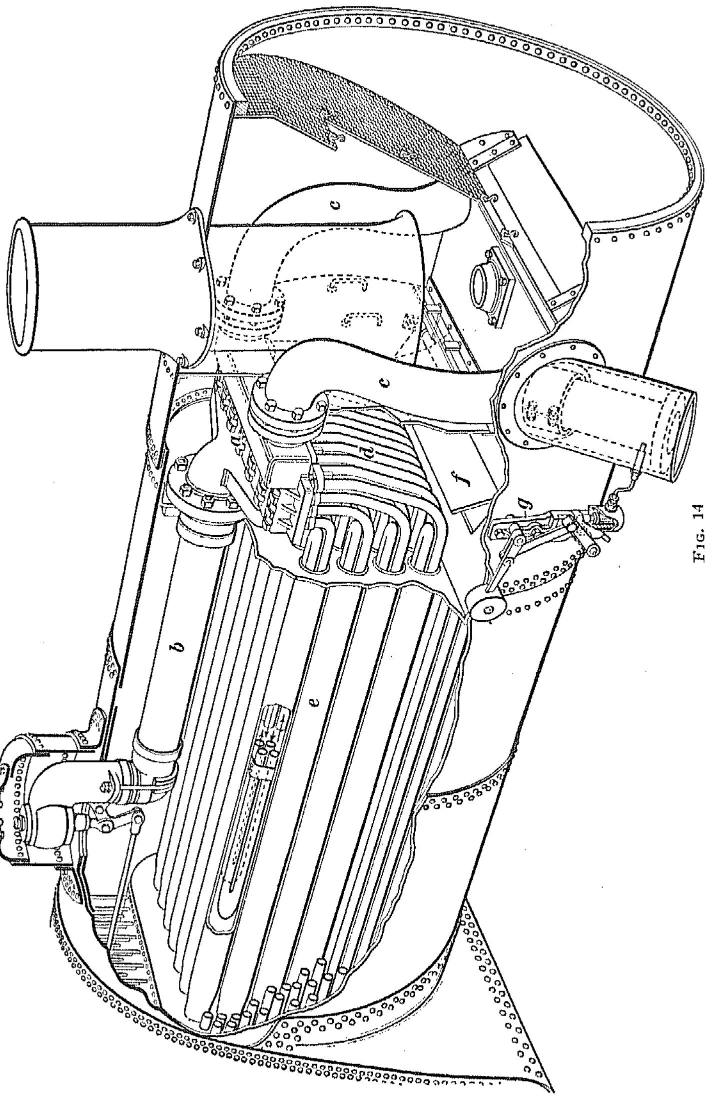



FIG. 14

pipes. The interior construction of the superheater header is given in Fig. 16, in which the top of the header is shown partly broken away. The header *a* contains a passageway *g* to which the compartments *j* connect, and a passageway *h* to which the compartments *i* connect. The passageway *g* communicates with the dry pipe, so that, with the locomotive in operation, the compartments *j* fill with saturated steam. The communication between the saturated-steam compartments and the compartments *i*, which are the superheated-steam compartments, is made by the superheater units, one shown. One end of a unit is connected to a circular opening in one compartment, and the other end is connected to a similar opening in an adjoining compartment. The superheater header is carried at the ends on header

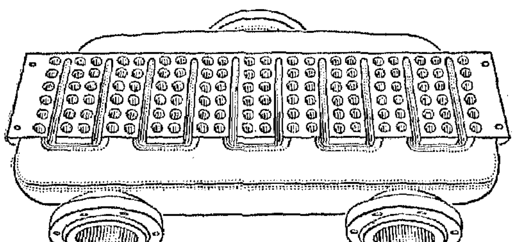


FIG. 15

supports that are bolted to the smokebox. The heads of the unit bolts are shown at *l* and the slots in the header through which the bolts pass are indicated by *m*.

**57. Superheater Units.**—The purpose of the superheater units, one of which is shown in Fig. 17, is to convey the saturated steam away from the saturated-steam compartments in the superheater header, and return it as superheated steam to the superheated-steam compartments in the header. The superheater units are placed within the superheater flues, and the heat of the firebox gases in passing through the flues is imparted to the steam in the superheater units, thereby superheating it.

Each superheater unit, in which the actual superheating is done, consists of four cold-drawn seamless steel tubes, carried as a cluster in each of the enlarged boiler flues that replace the standard 2-inch flues. The four sections of each unit are made

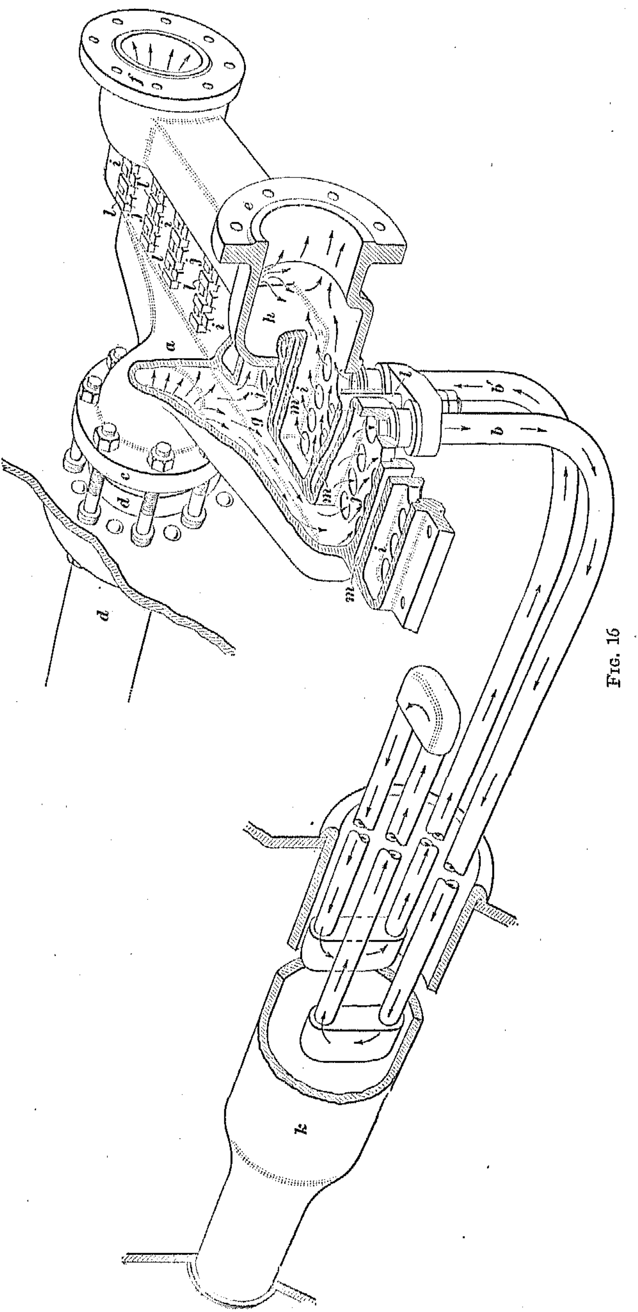


FIG. 16

into a continuous tube by forging the tube ends into a return bend in such a way as to permit a free flow of steam and also offer a minimum obstruction to the passage of hot gases through the flues. The return bends are forged integrally with the unit and from the same metal of which the unit itself is fabricated in a machine-forging operation, no oxy-acetylene or electric welding whatever being used. The steam enters the unit at one end *a*, Fig. 17, and leaves it at the other end *b*, passing through the unit as indicated by the arrows. The loops are doubled so as to increase the velocity at which the steam flows through the unit, in order to give a better degree of superheat, and also to protect the units from overheating.

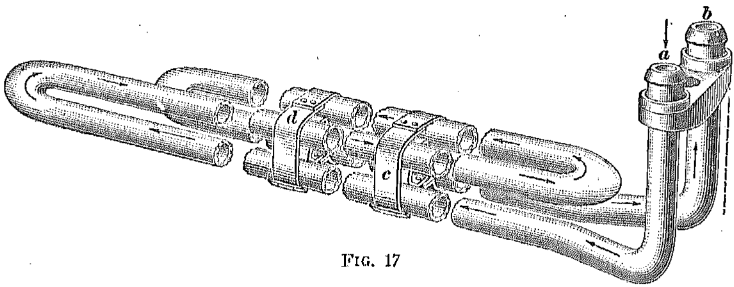
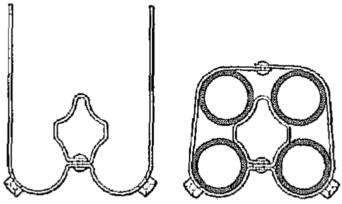



FIG. 17

The band *c* holds the pipes together and prevents them from moving. The support *d* is used for the same purpose, and in addition it has feet that hold the unit in the proper position in the superheater flue and also prevent the unit from vibrating in the flue.

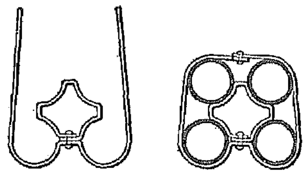
**58.** The proper application of the bands and supports is very important. Any vibration of the unit in the flue will tend to break the joint between the unit pipe and the header and permit steam to escape into the smokebox. Also, if bands are used where supports should be used, the unit will rest on the flue, so that this part of the unit will not have the proper contact with the hot gases, and cinders and soot will have a greater opportunity to collect and block the flue. One band is required for each unit and is placed near the front, but the number of supports required depends on the length of the units, and they may number from one to four. Confusion sometimes exists as to

the difference between a support and a band. The difference can be noted by considering Figs. 18 and 19. The former shows



(a) (b)

Fig. 18



(a) (b)

Fig. 19

a support before and after application, and the latter shows a band before and after it is applied to a unit.

**59.** The through-bolt method of securing the superheater units to the header is shown in Fig. 20. The units are attached to the header by means of clamped metal-to-metal ball joints. The unit ball ends fit into ground 45-degree conical seats in the header and are held in place by drop-forged unit clamps *a* and bolts *b* of heat-treated steel. The illustration also shows the unit end washer *c*, the unit bolt washer *d*, and the unit bolt nut *e*.

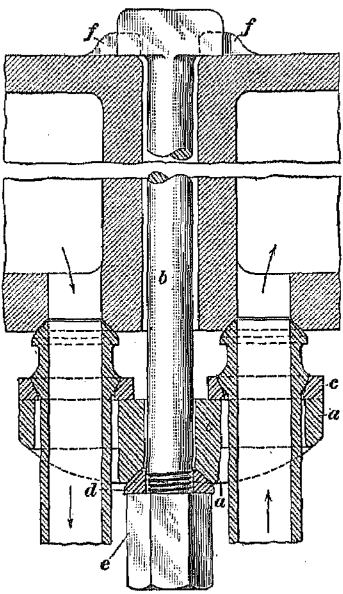



Fig. 20

The ball joint permits of quick and easy application or removal of the units without special tools. The joint is flexible, remains tight under the severest operating conditions, and is easy to adjust and maintain.

The clamps and the washers for the ball joints are made of steel and the bolts are special heat-treated alloy steel with a minimum tensile strength of 100,000 pounds per square inch.

Slight variations in the shape of the units or in their application to the superheater flues, or other causes may prevent the units from being applied to the superheater header in exactly a vertical position. However, the head of the bolt *b* should make a bearing all around on the top of the header. The ball joints that the pipes make with the unit end washers *c*, as well as the ball joint that the bolt washer *d* makes with the clamp *a*, permit the unit to be applied slightly out of its true position, if necessary, without moving the bolt out of a vertical position. The ball-shaped ends of the units permit them to be moved slightly out of their vertical positions during application, if necessary, and still have the joints steam-tight. The unit clamp *a* and the

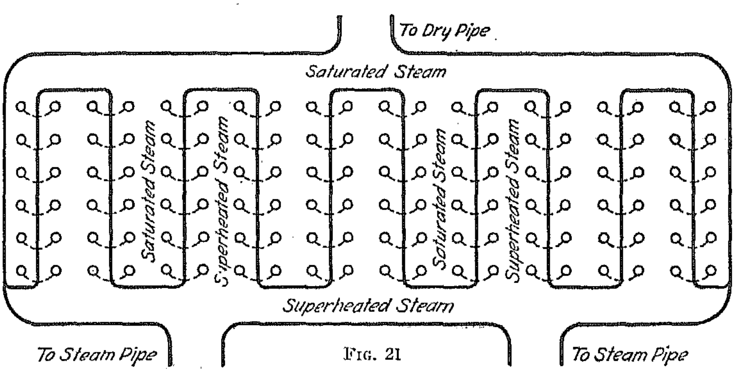



FIG. 21

unit end washer *c* are applied to the pipes before their free ends are forged together. The bolts *b* are passed up through the header from the bottom, then after being given one-quarter turn they are held from turning by the stops *f*.

**60. Arrangement of Units at Header.**—The conventional view in Fig. 21 shows the arrangement of the superheater units at the superheater header. It is assumed that the header is viewed from the top and that its upper portion is removed so as to show the interior. The units are connected to the holes in the bottom of the header, and the dash lines indicate the holes to which the two pipes of a superheater unit connect.

The saturated-steam compartments in the header, as well as the superheated-steam compartments, are indicated as such.

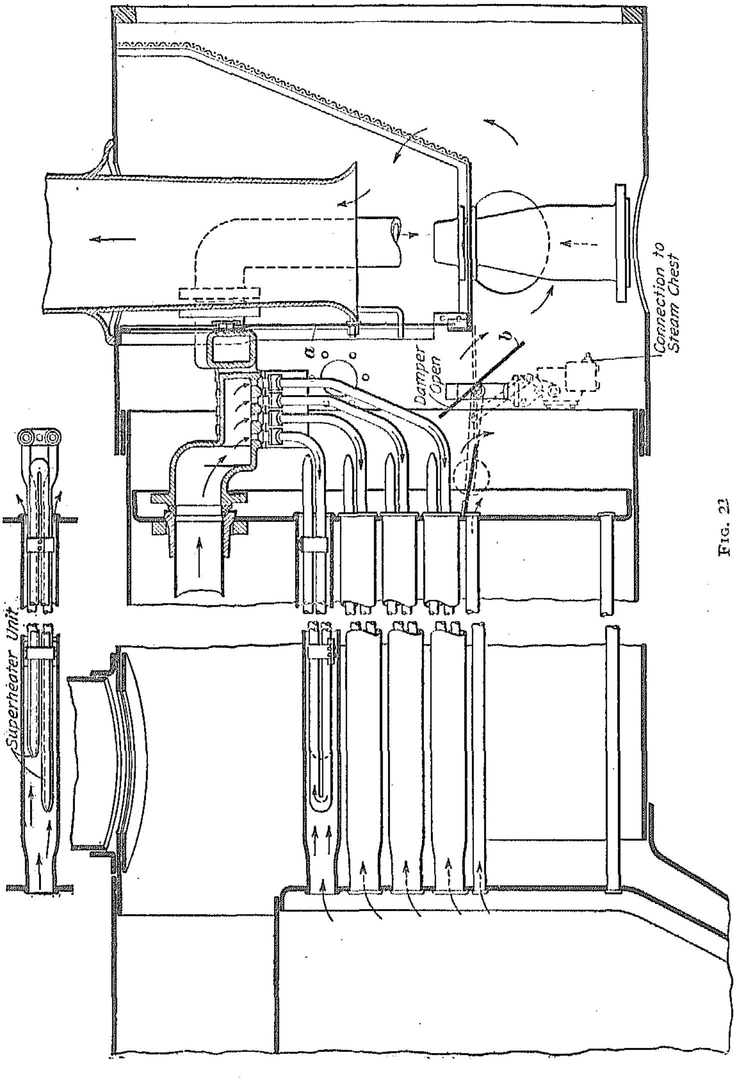



FIG. 21

The saturated steam passes from its compartments through the holes in those compartments to the inlet ends of the superheater units. The steam in its passage through the units is superheated and enters the superheated-steam compartments, from which it passes to the steam pipes. It will be noted that the two similarly located holes in each saturated- and superheated-steam compartment are connected by a superheater unit. There are 120 unit holes in the superheater, or 60 pairs; hence, 60 superheater units are required in piping the header.

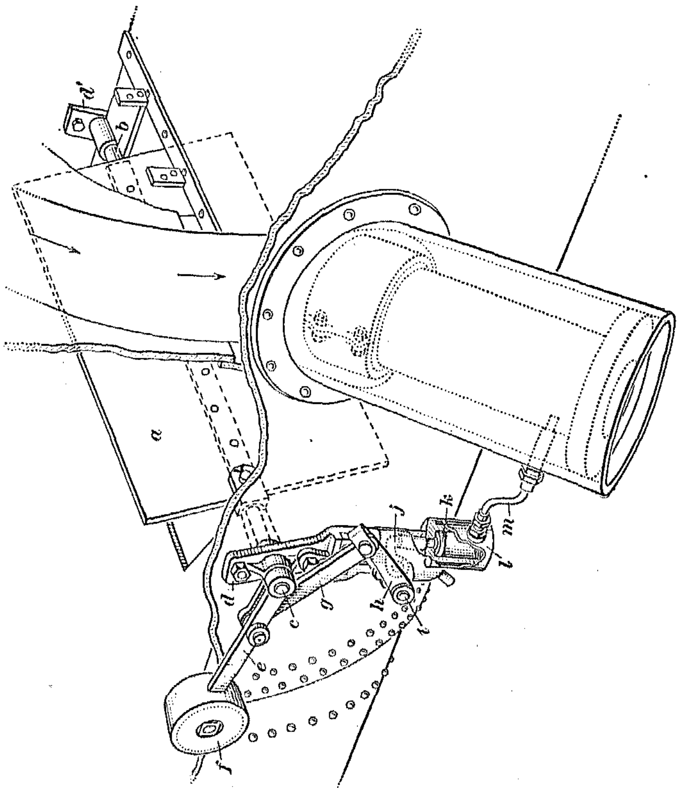



FIG. 23

**61. Superheater Damper.**—When the locomotive is working, the steam in the superheater units prevents them from

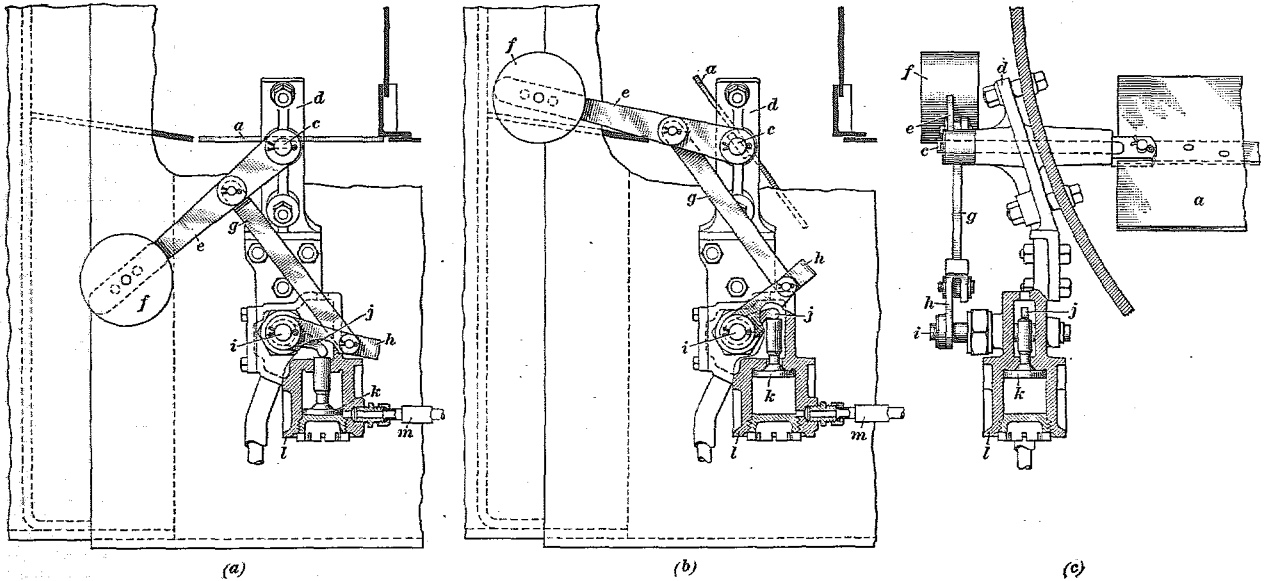



FIG. 24

being overheated by the firebox gases. There is no steam in the superheater units of the type A superheater when the throttle is closed, and, at such time, means must be provided to prevent damage to the superheater units. This is accomplished by partitioning off the superheater flues from the tubes in the tube-sheet by plates *a*, Fig. 22, and by providing a damper *b* at the bottom of the enclosure thus formed. With the damper closed, there is no draft through the superheater flues, and so they are not overheated. A mechanism is provided to open the damper as soon as the throttle is opened and to close the damper as soon as the throttle is closed.

As shown in Fig. 23, the damper *a* is supported by shafts *b* and *c* that are carried in bearings *d* and *d'*; the former is secured to the outside of the smokebox and the latter to the inside. A damper-shaft arm *e* (also see Fig. 24) with a counterweight *f* at the extreme end is keyed to the end of the shaft *c*.

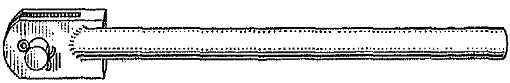


FIG. 25

One end of the damper-shaft link *g* is connected to a bearing on the damper-shaft arm and the other end is connected to the outside damper-cylinder arm *h*. This arm is keyed and pinned to a shaft *i* to which is also connected the inside damper-cylinder arm *j*. The end of this arm rests upon and is operated by the piston *k* in the cylinder *l*, which is in communication with the steam pipe of the locomotive through the pipe *m*. When the throttle is opened, the steam passes to the damper cylinder and moves the piston *k* upwards. The piston moves the inside damper-cylinder arm *j* upwards, which rotates the shaft *i*, and the outside damper-cylinder arm *h*. The link *g* then moves the damper-shaft arm upwards and opens the damper by rotating the shaft *c*. A view of the damper shaft *c* is shown in Fig. 25. The damper is held in the jaw of the shaft by the bolt shown.

**62.** It is particularly important that the damper mechanism be properly installed and maintained. If the mechanism does not close the damper properly, the gases will not be prevented

from entering the superheater flues when the throttle is closed. Also, if the damper does not open properly, the engine will not steam freely, owing to the obstruction that is offered to the passage of the gases.

The damper will sometimes open and close when the locomotive is drifting at short cut-off. With the reverse lever well hooked up, the cylinder compression will be higher than when the lever is farther down. Then when the valve opens the port and preadmission occurs, the air and steam in the cylinder will pass up into the steam chest, the steam pipe, and the damper cylinder, and the damper will open. This action may result in the return bends of the superheater units being overheated to such an extent that they may burst when the throttle is opened, especially if any water is carried over into the units. The remedy is to drift with the reverse lever farther forwards in the corner.

**63. Operation of Superheater.**—The operation of the superheater will be explained by referring to Fig. 16, in which the superheater header is shown partly broken away and with one superheater unit connected to it. The saturated-steam compartments are indicated by $j$ and the superheated-steam compartments by $i$, and, as already explained, one pipe $b$ of each superheater unit is connected to an opening in a saturated-steam compartment and the other pipe $b'$ is connected to a similar opening in the adjoining superheated-steam compartment.

The passageway $g$ and all the saturated-steam compartments $j$ fill with steam from the dry pipe $d$ as soon as the throttle is opened. The steam then passes through each of the openings in these compartments to the pipe $b$ of a superheater unit, and is superheated in its passage through the unit by the gases that are passing through the flue $k$. The superheated steam returns to the header through the pipe $b'$ of a superheater unit and enters a superheated-steam compartment, from whence it passes into passage $h$ to the steam pipes that are coupled to the header at $e$ and $f$. The temperature of the steam is increased about 250° in its passage through the superheater, hence the steam must lose this degree of superheat before it begins to condense.

The superheating of the steam is not accompanied by any increase in the pressure, although the molecules of steam are now vibrating much faster. As already stated, the pressure will remain the same, provided the molecules of steam are permitted to move farther apart as they are heated. The constant withdrawal of the steam from the superheater to meet the requirements of the cylinders, gives the steam molecules in the superheater more room to expand as they are heated, hence there is no increase in pressure. Also, the steam drops slightly in pressure when it passes from the boiler and expands into the volume of the superheater, and this fact also helps to offset any tendency for the pressure to increase above normal. A superheater when properly designed will not cause the pressure to increase, neither will it cause the pressure to decrease.

## SUPERHEATER ARRANGEMENT WITH FRONT-END THROTTLE VALVE

**64. Reason for Arrangement.**—The throttle valve, when a superheater is used, may be placed in the steam dome as in ordinary practice, or it may be placed between the superheater header and the steam pipes to the steam chests. This location places the throttle valve at the front end of the locomotive; it is therefore known as a front-end or smokebox throttle valve.

A superheater with a front-end throttle valve has several advantages over one with the ordinary arrangement of throttle valve. When a front-end throttle valve is applied, the superheater damper and rigging are not used because, with the valve between the superheater and the cylinders, the superheater units are always filled with steam. Furthermore, at all times there are one or more of the auxiliaries and the blower working; therefore, steam is flowing through the units when the main throttle valve is closed, thus affording protection to the superheater units. Only when such protection is afforded, however, may the damper be dispensed with without the danger of overheating the superheater units. From the viewpoint of maintenance the presence of steam in the units at all times, greatly reduces the possibility of burning the unit ends and tends to protect the equipment and prolong the life of the tubing.

Superheated steam can also be supplied to the locomotive auxiliaries, such as the headlight-turbine, air compressor, water pumps, stokers, steam grate shaker, blower, whistle, etc. Tests indicate that the use of superheated steam in the auxiliaries decreases their demand on the boiler by 40 per cent., which is equivalent to a saving of from 4 to 8 per cent. of the total fuel burned. Also, the front-end throttle valve enables the locomotive to be more easily controlled because of the small volume of steam that is left to pass to the cylinders when the throttle is closed. Therefore, slipping can be stopped almost instantly; also, the locomotive can be spotted more easily.

The front end throttle valve may be incorporated with the type E superheater header as explained in the following sections or it may be separate from it.

## ELESCO TYPE E LOCOMOTIVE SUPERHEATER

**65. Difference Between Type A and Type E Superheaters.** The difference between the Elesco type A and E superheaters consists primarily in the size and disposition of the superheater units and the boiler flues. Each superheater unit comprises eight tubes of a diameter of $1\frac{1}{8}$ or $1\frac{3}{16}$ inches, two of which tubes are placed in a flue; four flues are therefore required to accommodate a complete unit. The superheater flues occupy nearly the whole flue sheet area, and are smaller than those used with the type A superheater, having an outside diameter of 3 inches, $3\frac{1}{4}$ inches or $3\frac{1}{2}$ inches. A larger number of units is consequently used than with the type A superheater.

The principal advantage of this arrangement is an increase of from 15 to 20 per cent. in the total gas area through the flues, an increase of from 35 to 40 per cent. in the steam area through the superheater, and an increase of from 80 to 100 per cent. in the superheating heating surface.

The increase in the heating surface not only imparts a higher degree of superheat to the steam, but it also has the effect of evaporating the large percentage of moisture that is carried over into the superheater owing to the restricted steam space in the large modern boilers. Because of clearance limitations, the steam dome has become smaller and smaller, so that on large

locomotives practically all there is of a steam dome is a cap that serves as a manhole for entering the interior of the boiler. A boiler of this construction is therefore limited in steam space and the percentage of moisture carried over to the superheater is much greater than it is on the older or smaller locomotives, where the boiler is provided with ample dome or steam space, thereby providing much drier saturated steam to the superheater.

The type E superheater gives a degree of superheat from 250° F. to 300° F. as compared with a degree of superheat of from 200° F. to 250° F. obtained with the type A. The increase

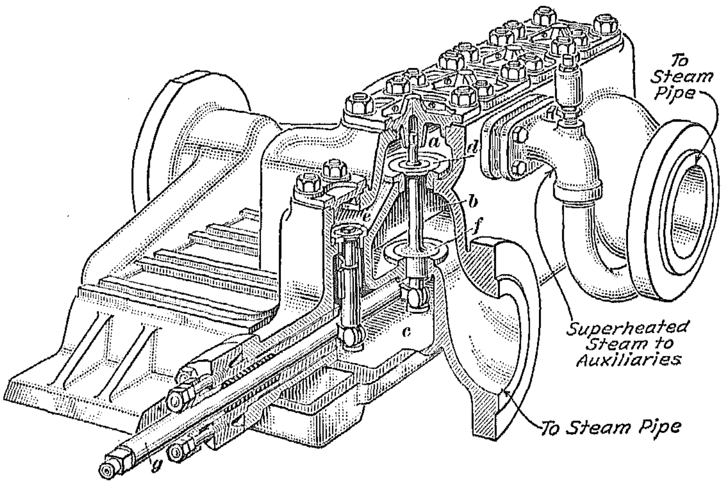



FIG. 26

in the steam area through the superheater lessens the drop in steam pressure from the boiler to the cylinders.

The front-end throttle valve is used with the type E superheater, hence a damper and a damper mechanism is not necessary.

**66. Superheater Header.**—With the type of header used with the type E superheater, shown partly broken away in Fig. 26, the American multiple throttle is integral with the casting. The only change, as far as the arrangement of the superheater is concerned, is that the unit bolts are reversed, the nut being placed on top of the header instead of below the clamp.

With this type of header a smokebox coverplate is provided above the header as shown in Fig. 27, so that the unit bolt nuts as well as the throttle are accessible from the top of the smokebox. The American multiple throttle, as the name implies, consists of a series of small single-seated valves that are located in the forward part of the superheater header. There are three longitudinal chambers that extend across the front of the header and that are arranged one above the other. The upper chamber *a*, Fig. 26, is part of the superheated-steam section of the superheater header. At the front of this chamber are the flange

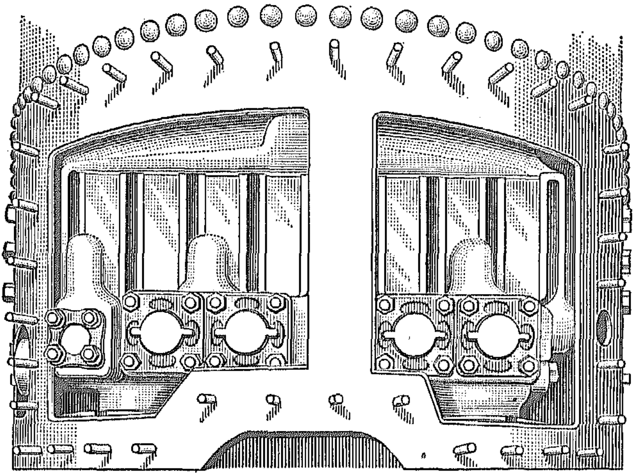


FIG. 27

connections for the pipe that conveys steam to the auxiliaries, so that superheated steam is always available for them. The middle chamber *b* connects to the steam pipes; the third chamber *c* is without outside connection and is used entirely for balancing. There are three or more main valves *d* each $4\frac{1}{8}$ inches in diameter; these admit steam from the upper to the middle chamber. At the extreme left is a smaller valve *e* known as the pilot valve, that admits steam from the upper chamber to the balancing chamber. Each of the main valves has a balancing piston *f* that fits loosely in the passage between the middle chamber and the balancing chamber.

**67.** The valves are opened and closed successively by a cam-shaft *g* and they are so balanced that a minimum effort is required to lift them. At the first movement of the camshaft the small pilot valve *e* is lifted, which, because of its small size, offers little resistance. Steam is then admitted into the balancing chamber and under the pistons *f* of the main valves. The areas of the pistons are such that the main valves are now nearly balanced. As the cam-shaft is rotated further the first main valve is lifted, thereby allowing a small amount of steam to pass

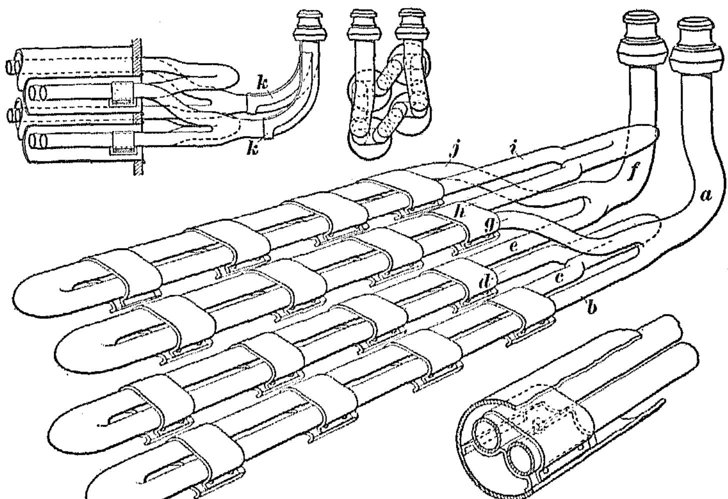



FIG. 28

to the cylinders. A further rotation of the shaft opens the main valve at the opposite end of the chamber and continues the lifting of the first valve; thus, in succession all of the valves are lifted. The closing takes place in the reverse order. By the successive opening and closing of the valves, positive graduation of the steam is provided to the cylinders.

The valves can be repaired with the boiler under pressure; to do so it is only necessary to close the shut-off valve in the dry pipe at the steam dome, and then open the throttle and cylinder cocks to drain the steam from the superheater units.

To guard against excessive pressure in the superheater should the shut-off valve be closed without opening the throttle and the

cylinder cocks, a safety valve is provided in the pipe that conveys superheated steam to the auxiliaries.

**68. Unit Arrangement.**—A view of a superheater unit used with the type E superheater is shown in Fig. 28. With the type A superheater, a complete unit consisting of four pipes is placed in each flue, whereas with the type E superheater, a unit comprises eight pipes, with two in each flue, therefore a single superheater unit occupies four flues.

The saturated steam enters the pipe *a* and passes through the pipes *b* and *c* in one flue to the pipes *d* and *e* in another flue, thence to the pipe *f*. Also, some of the steam from the pipe *a* passes through the pipes *g* and *h* in one flue, thence through the pipes *i* and *j* in another flue, and returns as superheated steam through the pipe *j* to the pipe *f*. The shields *k* prevent the cinders that pass through the flues from cutting the pipes.

As the superheater flues are smaller than with the type A superheater, the gases are divided into smaller streams, so that more of their heat is available for superheating the steam. Aside from this, there are only two pipes of a unit in a flue, the results being a higher degree of superheat than with the type A superheater.

With some installations of the type E superheater, none of the ordinary boiler tubes such as are used entirely with saturated-steam locomotives are employed; the pipes for conveying the gases to the smokebox are all superheater flues. With other installations, a few of the ordinary type of tubes are used.

**69. Pressure in Type E Superheater.**—With the type E superheater and the throttle closed, the pressure of the steam in the superheater will increase slightly, as the steam cannot expand except toward the boiler. However, the volume of steam in the superheater is so small as compared with the steam volume in the boiler, that the slightly higher pressure of the small volume in the superheater does not perceptibly affect the pressure of the larger volume in the boiler.

**70. Arrangement.**—A sectional view of the casting of a Chambers front-end throttle valve in the smokebox forward of

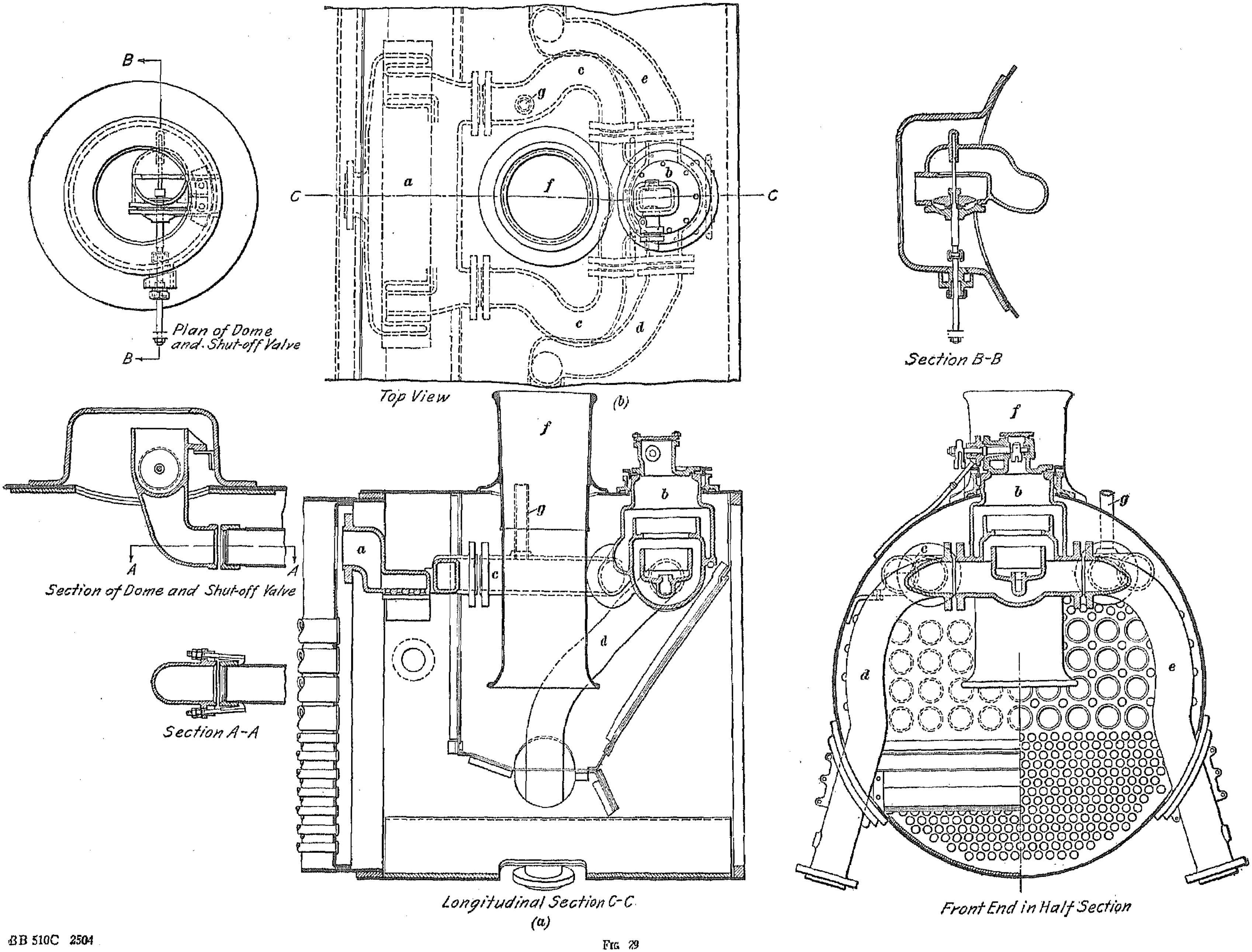



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Fig. 29

the stack is given in Fig. 29. In the top view (*b*) is shown the arrangement of the piping to the throttle valve. The superheater header *a* is connected to the throttle valve *b* by the two pipes *c* that curve around the smokestack *f*. The steam pipes *d* and *e* connect the throttle valve to the steam chests. Superheated steam for the operation of the locomotive auxiliaries is

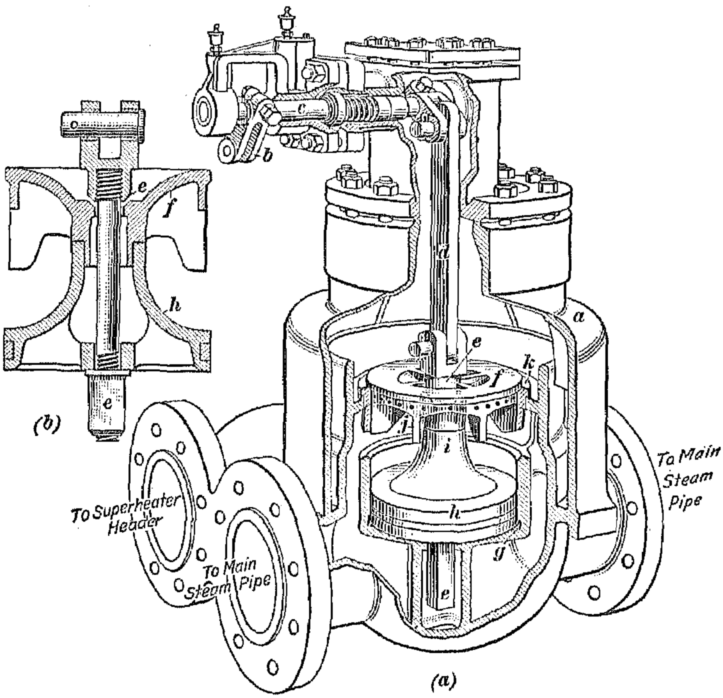


FIG. 30

conveyed back to the cab turret through the $2\frac{1}{2}$-inch pipe *g*. The end of the dry pipe in the steam dome is provided with a shut-off valve, so as to make it possible to repair the throttle valve if necessary, with the boiler under pressure.

The Chambers throttle valve is shown in its throttle box *a* in Fig. 30 (*a*). The opening movement of the throttle lever is transmitted through the throttle rod to the crank arm *b* on the operating shaft *c*. The shaft then lifts the link *d* and the pilot

valve *e* (also see view (*b*) ), and permits steam to pass through the center of the main valve *f* to the chamber *g* under the balancing piston *h*. The pilot valve next pulls the balance piston upwards until its end comes in contact with the main valve at *i* and unseats it. The steam first passes through the series of small holes shown in the main valve; as the valve continues to lift, the steam passes through the openings between the wings *j*, two shown. The main valve rests on a ring seat *k*; the ring seat when removed permits the balancing piston to be applied, this piston being larger than the main valve *f*.

## MAINTENANCE

**71. Cleaning Superheater Flues and Units.**—Certain kinds of fuel and improper drafting of the locomotive are responsible for dirty flues. These conditions interfere with and reduce greatly the steaming of the locomotive, and also materially affect the superheating of the steam that is passing through the units. If a superheater unit is cut off from the gases, the steam will pass through the unit without being superheated. Every unit that is cut off from the action of the gases is responsible for a reduction in the capacity of the superheater. One flue completely plugged in a twenty-five unit superheater makes 4 per cent. of the superheating surface inactive as well as the evaporating surface of the flue itself. Thus, the effect of several units cut off in this manner will very quickly show up in the performance of the locomotive. It is imperative, therefore, that all dirt, ash, and cinders be prevented from accumulating in the flues, and that the inside of the flues and the outside of the units be kept clean and free from soot. Any accumulation of clinkers or cinders on the back end of the return bend should be broken off and removed from the firebox end.

**72.** To clean a flue, the procedure is as follows: Insert a $\frac{3}{8}$-inch or $\frac{1}{2}$-inch air pipe at the firebox end of the flue, turn on the air, which should be at a pressure of 100 pounds or more, and gradually work the pipe forwards under the superheater unit and for the whole length of the flue, thereby allowing the air to blow the dirt ahead of the cleaning pipe out of the front

end of the flue and out through the damper, which must be open during the operation. The damper must be closed afterwards.

When a flue is plugged up, dig the dirt out from the back end until the return bends of the unit are reached, drawing the dirt back into the firebox. Then, if possible, force the cleaning pipe through the dirt to the front end of the flue. Apply the air and slowly draw the pipe back about 2 feet so as to allow the air to clear the front end of the flue as it is drawn back. Next, shove the pipe forwards again to insure the front end being cleaned, then draw it slowly back 2 feet farther than the previous time. Continue this process until the entire flue is cleaned.

If the air pipe cannot be forced through the flue to the front end, the flue will have to be cleaned from the back end. Force the pipe about 6 inches into the dirt and turn on the air. This will blow the dirt out with considerable force, which must be guarded against to prevent injury to the man handling the pipe. A 9-inch disk of wood with a hole in its center that is a close fit for the air pipe, will prove a good guard. It should be about ½ inch away from the end of the flue when the air is turned on.

After the flues have been cleaned, use a good bright flashlight to inspect for cleanliness. Holding a torch flame at the firebox end of the flue to see whether the flame is drawn in does not give trustworthy evidence that the flue is clean. If the flame is drawn in, it indicates simply that there is an opening through the flue, though the whole bottom of the flue may be filled.

Washing flues is preferable to blowing them with air and is much more satisfactory. By washing at regular boiler washout periods and with the same crew and apparatus, the flues can be kept clean and in a more satisfactory condition from washout to washout. After washing the flues, insert an air hose in each one to insure drying up the moisture; otherwise there will be difficulty when firing up.

**73. Testing the Superheater.**—Leakage of steam from the flues, flue-sheet seams, rivets, superheater units, or the dry-pipe and steam-pipe joints, has a tendency to cut through any other part of the metal that it strikes against, so that such a leak may

result in serious damage unless it is promptly discovered and remedied. The only reliable way to detect such leaks in time to prevent damage is to test the superheater units, steam pipe, exhaust pipe, and dry pipe, at regular intervals, by use of water at a pressure of 100 pounds or more. In many cases serious leaks have been found in the front end that must have existed for some time without resulting in a steam failure and without affecting the steaming of the locomotive sufficiently to cause a "poor steaming" report to be made.

The tests for leaks should be made at quarterly inspections. If the boiler is warm, hot water should be used for the test. The water can be admitted into the boiler either through the connection used for filling the boiler or through the blow-off. When more than 100 pounds pressure is obtained, a careful inspection should be made of the dry-pipe joints, steam-pipe joints, exhaust-stand joint, exhaust-nozzle tip, the joint between the superheater units and the header, and all seams and flues in the front end. At the back end, the return bends in the superheater units should be inspected, and any water in the bottom of the flue under the unit ends should be considered an indication of a leak in the unit.

### *SUPERHEATED STEAM PYROMETER*

**74. Purpose.**—The purpose of the superheated steam pyrometer is to indicate to the enginemen the temperature of the steam going to the cylinders. Locomotive superheaters are designed to develop steam temperatures of 600 to 750 degrees Fahrenheit, and these temperatures should be maintained for the greatest efficiency in operation. Any reduction of such temperatures when the locomotive is working is an indication that certain conditions are interfering with the proper performance of the superheater and should be corrected.

**75. Principle of Operation.**—The operation of the pyrometer is based on the principle that if two dissimilar metals are welded or fused together and the joint thus made is heated, a minute current of electricity will be generated. The current is led away by wires to a measuring device called an indicator.

This indicator actually measures the voltage generated but, as any change in voltage is caused by changes in temperature, the dial of the indicator is marked in degrees.

An assembly of two parts of dissimilar metals or wires is known as a thermocouple or heat couple, shown in Fig. 31, in which the two wires are shown fused together at *a*, and *c* is the outlet for the two wires that connect the thermocouple to the measuring device. The thermocouple is placed at the point where the temperature is to be measured. The complete pyrometer assembly then comprises a thermocouple, a measuring device or indicator, and the two wires connecting these two parts.

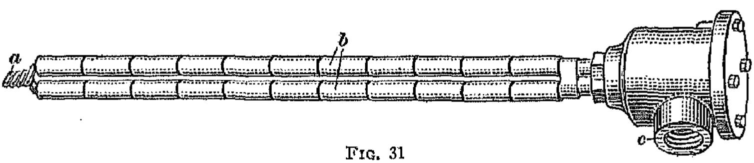


FIG. 31

The thermocouple is referred to as the hot junction of the pyrometer assembly, and the ends of the thermocouple wires, where connected to the indicator, as the cold junction. The flow of current is from the hot junction to the cold junction and return. The electric current generated is proportional to the difference in temperature between the hot and cold junctions of the thermocouple, *the former being at the steam* fixture and the latter at the indicator. The slightest variation in the temperature of the steam immediately affects the previous voltage set up by the thermocouple and is registered in degrees on the dial of the indicator.

**76. Pyrometer Assembly.**—A view of the assembly of the Model 496 superheated steam pyrometer, manufactured by the Superheater Company, is shown in Fig. 32 (*a*). The pyrometer equipment consists of three parts, the steam fixture *a* with a thermocouple *b*, the indicator, and the cable which contains the two wires connecting the thermocouple to the indicator. This cable is carried within a conduit pipe. The steam fixture is

screwed into the steam pipe, and exposes the end of the thermocouple or the hot junction directly to the flow of superheated steam.

A section taken through the steam fixture is given in (*b*) and shows the terminals *T-1* of the thermocouple to which the cable wires are connected.

**77. Sectional Views.**—A section through the cable case of the indicator is given in Fig. 32 (*c*) and shows the cable wires

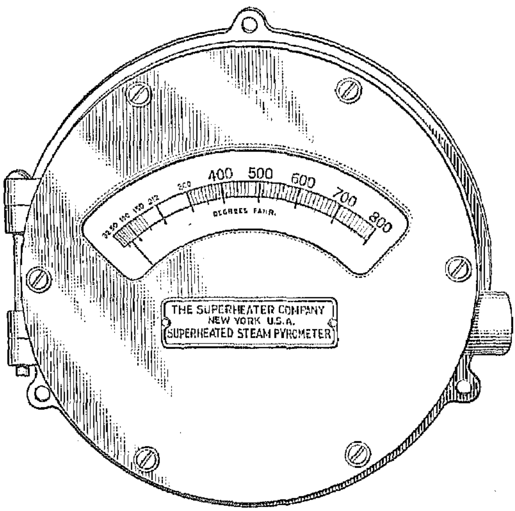


Fig. 33

connected to the terminals *T*; also the pyrometer zero adjuster *M*. This adjuster is used only when testing the pyrometer with a test set and the test discloses a variation of more than 10 degrees between the pyrometer reading and that of the set. In this event the seal wire *W-3* on the plate *N* is removed and the adjusting screw *Q* is turned until the pointer on the indicator agrees with the hand on the test set. Such adjustments are to be made only in the presence of a representative of the manufacturer. A vertical section through the indicator is given in view (*d*) and shows the cable coiled up in the back of the case because the cable is never to be shortened, the two terminals *T*,

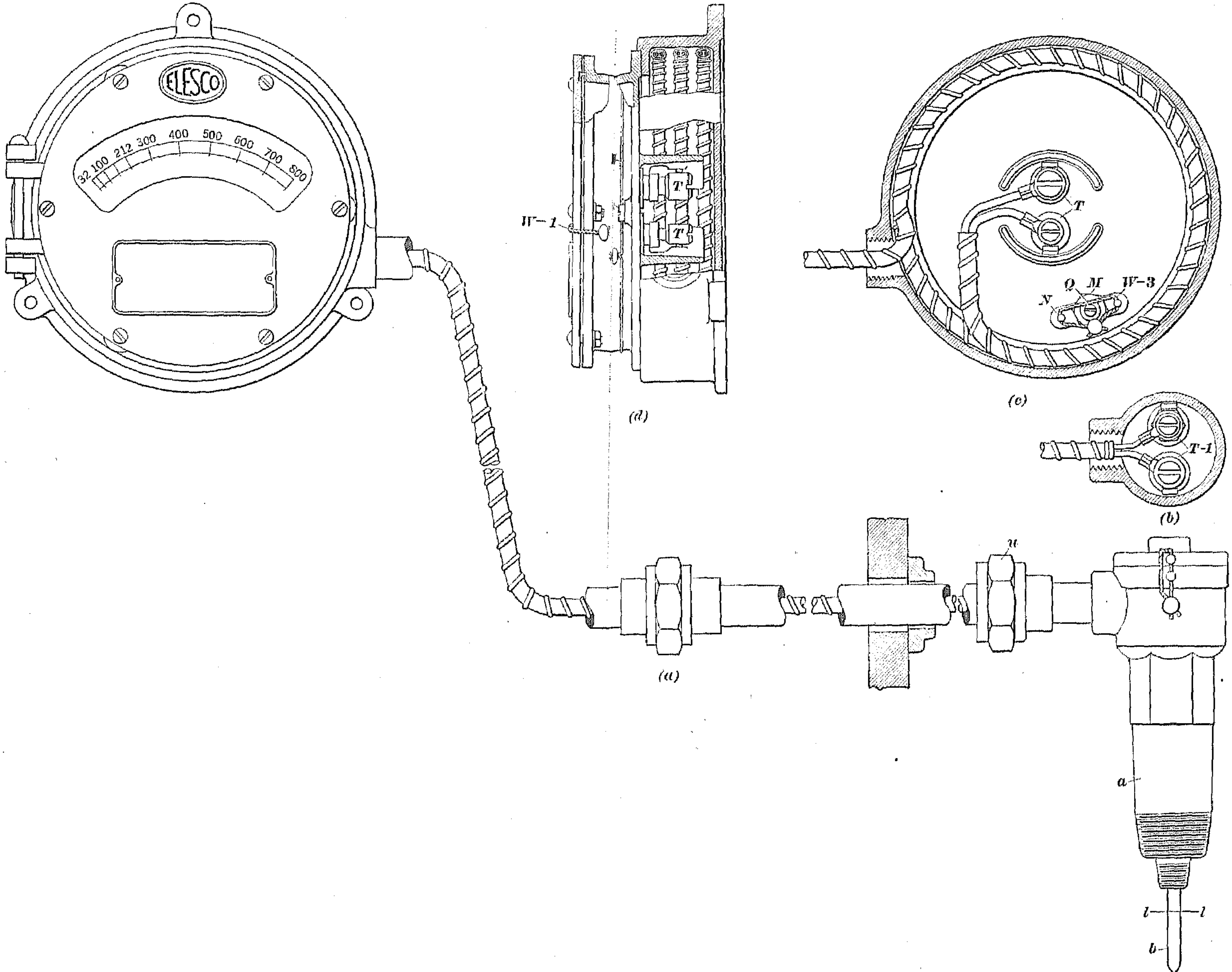


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Fig. 32

and the cover screws *S*, through which a sealing wire *W* is passed. The sealing wire *W-1* on the front cover is never to be broken.

The voltage generated by the pyrometer is very small and will be indicated only on an extremely sensitive measuring device, so that the indicator is really an instrument known as a *millivoltometer*.

The left-hand end of the dial, Fig. 33, indicates temperatures between 32° F. and 212° F., these two temperatures being registered when the engine is cold or partly fired up. The temperatures shown with the locomotive in service will vary between 600 and 750° F. The dial of the indicator is furnished with either the Fahrenheit or the centigrade scale, as desired.

**78. Pyrometer Indications.**—When the train is being started, the pointer of the indicator should move rapidly to the right until the temperature registers about 400° F. From this point on, the pointer should move less rapidly until the maximum temperature of 600° to 750° is registered. The rate of temperature increase will depend to a great extent upon the height of the water in the boiler and the condition of the fire. The locomotive should be operated in such a manner as to obtain the highest possible temperature and the indicator should be observed as closely for temperature variations as the steam gauge for changes in steam pressure.

**79. Conditions Affecting Pyrometer Indications.**—Any or several of the following conditions will cause the pyrometer to show a perceptible drop in the temperature of the steam: Water level in boiler too high; poor firing; superheater flues stopped up; air or steam leaks in the front end; improperly working damper.

Priming will occur if the water in the boiler is carried too high. The water that is then carried over into the superheater units will be evaporated there so that the temperature of the steam will be reduced.

Poor firing will cause a reduction in firebox temperature and hence in steam pressure; then the lower temperature of the steam will cause the pyrometer to indicate a decrease in

temperature. A portion or all of the superheater flues, if stopped up, will prevent the passage of the hot gases that superheat the steam.

Air or steam leaks in the front end will affect the draft of the locomotive and will interfere with the free passage of gases through the superheater flues. Also, this condition will reduce the steam pressure and thereby affect adversely the pyrometer reading. If a locomotive has a superheater damper that does not operate properly, the circulation of the gases through the superheater flues will be retarded and the superheat will decrease.

**80. Testing the Pyrometer.**—A complete test of the pyrometer can be made only by a special instrument designed especially for this purpose. However, either one or both of the following simple tests can be made without a testing device.

The first test is made by short-circuiting the indicator by connecting a short copper wire across the terminals *T*, Fig. 32 (*c*), in the back of the indicator case. The pointer should indicate approximately the temperature of the air surrounding the interior of the indicator. The second test is made by disconnecting the terminals *T-1* and the union *u* and removing the fixture from the steam pipe. Next, the terminals are connected again and the end of the steam fixture is immersed in boiling water up to the line *l-l*. The indicator pointer should then show 212° F. It is essential that the water be kept boiling during the test.